METAL PROGRESS

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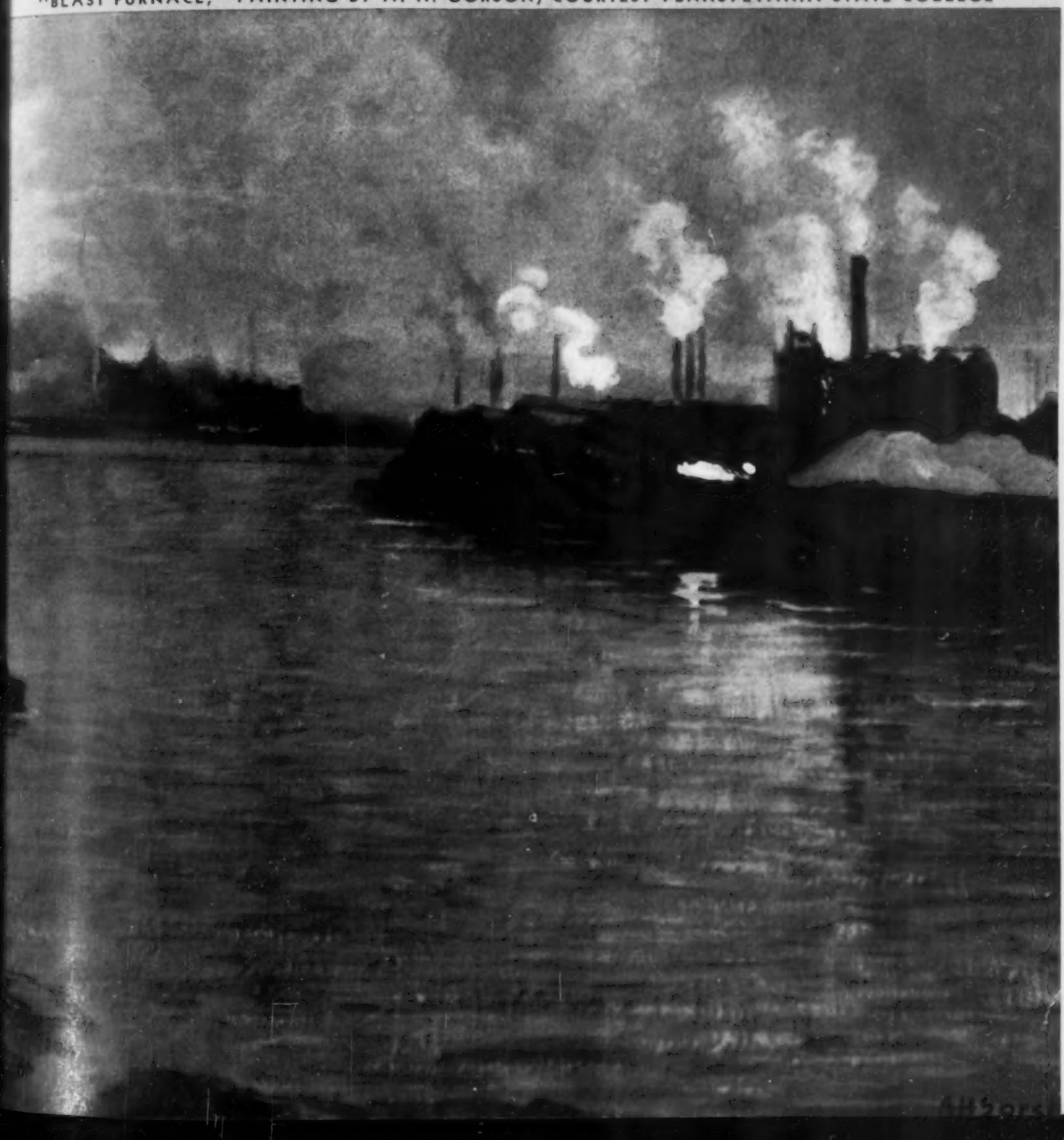

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Routine Inspection of Automotive Parts

By Joseph G. Gagnon

Chief Metallurgist

Hudson Motor Car Co.

Detroit

AN IMPORTANT PART of the duties of a metallurgist in a plant producing that wonderful creation of man's mind, the automobile, is to establish and supervise routine tests that come nearest to checking the service requirements. Much could be written on this subject, and most of it would be pointless unless all concerned had a vivid appreciation of the real significance of the tests imposed. Unless we have the cooperation of the workman and the inspector, all our efforts will go for naught.

After a specific unit has been designed, materials and heat treatment specified and the blueprints released for production, it is necessary that the fabricating, machining, and heat treating be checked so as to ascertain whether or not the specifications are being adhered to. With that in mind, the metallurgist, through his knowledge of the material specified and its service requirements, designates a specific method of testing, be it chemical or physical or both, which he thinks will best be suited to eliminate any possibility of failure of the part or assembly during service.

Methods and instruments for routine tests must be selected with the size, shape and surface condition of the part in view. It so happens that various tests for hardness have proven to be comparisons (somewhat crude, it may be) of the true physical properties of the part. However, they must be resorted to, because the only other alternative would result in so mutilating the part as to make it unusable. Chemistry and heat treatment must be constant so as to come within the narrow limits as set up in certain physical specifications; these narrow limits are not always indicative of service requirements, but may be actuated from an economic standpoint.

It is well to mention at the outset that test results are comparable only to that degree of accuracy with which they have been made.

Let us assume that an important forging such as a transmission gear is being purchased.

The forging company's representative is told by the purchaser's metallurgist that his steel supplier is to submit, together with the ladle analysis, samples from the heats that will be used. The laboratory analyzes and approves the steel, and the mill rolls it into whatever sec-

tions have been specified by the forge company.

Upon receipt of the bars, additional samples are submitted by the forge company to our laboratory for additional checks. These are supplemental to their own chemical checks. Duly approved, the bars are fabricated into forgings and the blanks shipped to our plant.

Before being released to the heat treat for normalizing, additional forgings are analyzed, so we can assure ourselves that the chemistry is to the original analysis. Of course, this procedure does not apply to all forgings — only those that we consider vital or where service and design require it.

Other forgings made of a definite S.A.E. steel, and not considered vital, are given a Brinell test, which, by a hardness comparison table compiled from extensive tests on the same part and the same steel, gives a satisfactory check on the material in question. Only a certain percentage are Brinelled, but of course the forging practice and reliability of the forge shop must be well known — otherwise these latter tests mean nothing.

Purchase of Bar Stock

When bar stock is purchased, preliminary samples from the mill are not required, as there are no manufacturing costs prior to receipt in our plant. Several bar-ends are taken at random from each shipment, analyzed for the several important elements and these are checked against the ladle analysis of the steel as submitted by the steelmaker. If these agree, within the limits set up by the metallurgical department, the bars are released for manufacture. (Should a mix-up occur, spark testing by a competent operator might be resorted to for sorting the stock.)

In my opinion, some elemental analyses are just a waste of money and time. Why, for instance, should sulphur and phosphorus be checked in alloy steel — or even plain carbon steels? The tolerances allowed the steel companies are such that these impurities can be held within the maximum limits very easily. Do not forget that the steel companies have not been idle during this past decade, and their practice in the making of carbon steels is as good as was some alloy practice years ago.

It was noted above that rough forgings are inspected by the Brinell hardness test. Here would be a logical place to describe hardness tests and equipment, but it is so large a subject as to warrant separate consideration. Suffice it to say that the common tests used in inspection are *(a)* the file, which is a most rapid and practical tool for hardened surfaces, and the only one for inspecting considerable areas; (*b*) the scleroscope, which is good for testing superficial hardness without disfiguring the surface; (*c*) the Rockwell, a flexible machine of great value, especially on semi-finished and finished work; (*d*) the Brinell machine, which most nearly indicates tensile properties of steels up to medium high hardness (say 477).

Tests Other Than for Hardness

Other methods of test, used on representative samples sent to the laboratory for study, include tension and torsion tests, impact, fatigue, macro-etch, McQuaid-Ehn test, and salt spray. These are all well known and are adequately described in the ASM Metals Handbook, so nothing more than a few remarks about precautions need be made here.

Tensile and torsion tests are affected by several variables which should be carefully watched, notably speed of testing, eccentric loadings, damaged knife edges. Often a test bar gives a higher value per unit of area than the piece from which it was cut could withstand in some region due to sharp corners or other mechanical irregularities. The proper procedure in such a case would be to design a fixture to load the entire part so this weaker section would carry the principal load.

Impact Tests — If the part is subject to varying shock loads, the use of impact testing can be resorted to. It is often more important to have a high impact value than a high tensile strength.

Macro-Etching — One of the best-known laboratory testing methods which is often employed by shop men is macro-etching. This usually consists of immersing parts or sections in a hot muriatic acid solution, although sulphuric acid can be used and often is. In either event the results are much alike if commercially pure acid is used, and serve three purposes:

1. Surface inspection for seams, laps, mechanical marks, scratches, heat treat cracks, and even grinding wheel checks.
2. The determination of flow lines in forgings (sectioned and smoothed).
3. Inspection of cross-sections of parts for internal flaws and segregations.

In most cases the parts after being etched

sufficiently are examined for flaws, sometimes with a hand glass. Remember that much misinformation can result from poor etching, particularly if fine surface imperfections are being sought, when an etch which removes no more than 0.002 to 0.004 in. is ample.

In some instances, due to high residual stresses which cause active acid action (an extremely high amount of cold work will result in this condition), flaws will be indicated where in truth no flaw existed. This condition can be overcome by heating suspected parts to 700° F. before etching. The lines of working will still show, but the acid will not eat holes in the specimen.

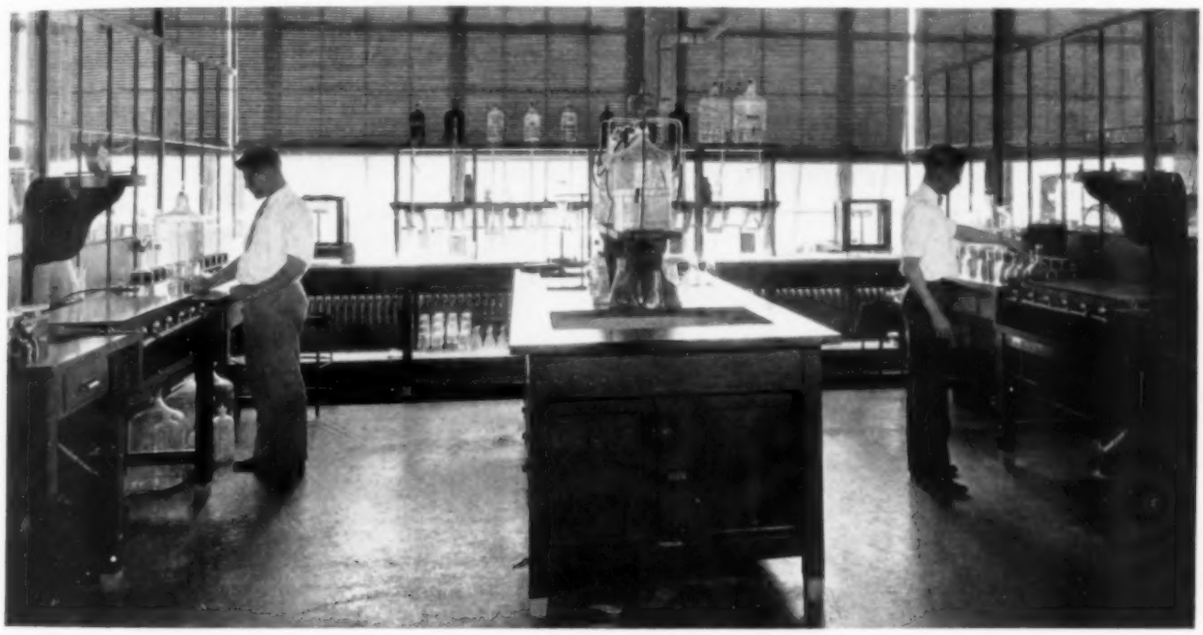
The proper use of this test will often be a stepping stone to higher quality parts.

McQuaid-Ehn Test for Grain Size — We inspect for grain size after the steel has been carburized at a definite temperature, but do not take into account the fact that if the part has been severely worked and heat treated, the original grain size might be considerably changed. True, grain size is the controlling factor for results such as machinability, hardenability, distortion and physical properties, but do we all speak the same language when we talk about a given grain size number? I believe that much more work can be done along this type of routine inspection.

Salt spray is used mostly for inspecting plated ware. Evaluation of corrosion resistance is one highly controversial problem, but after all, we are guided by field service in the setting up of test standards. Judging from my service reports, I will say that any part successfully withstanding a 45-hr. salt spray will withstand the elements over a long period without any noticeable effect on the finish.

Exception is usually taken to the test on the basis that the part is not subjected to salt spray in service, but if you will inspect the outside hardware of some cars after a winter's driving on streets where salt has been spread around to melt ice, or cars in service along the seaboard, you will agree that salt plays an important part in the breaking down of plated parts.

The alternatives are to specify a definite thickness of plate or a certain amperage for definite time. How are you going to be sure, from subsequent inspection methods, that the base metal is not porous or improperly polished prior to plating? How can you tell, without numerous checks, and those only at an economic loss, whether or not the plating is uniform? The answer may be closer inspection of the



Metallurgical Analysis Booth in Laboratory of Hudson Motor Car Co., Where Steels Are Analyzed for Various Alloying Elements and Normal Impurities. Ten such booths, with special equipment permanently mounted, are available

semi-finished product and laboratory control of the plating solutions. What if there is no laboratory in the plating shop doing your work?

Routine Testing Prior to Machining

Ordinarily parts in process of manufacture in our own plant require no hardness test prior to heat treatment — routine inspection of the raw material being sufficient. However, forged parts made outside are checked in various ways, as outlined above, and released to the heat treat. Again referring specifically to transmission gears, a definite normalizing cycle is adopted, dependent upon analysis and inherent grain size, in order to remove forging strains and so rearrange the grain structure that it will machine as economically as possible and obtain a finish acceptable to the inspection department.

This cycle may consist of heating the material to a definite temperature, holding at that temperature for a specific time, quickly cooling to another temperature, gradually cooling in the furnace to a definite temperature, and then cooling the rest of the way in air.

Depending again on analysis, a definite hardness is the result of this operation, and this is a most convenient method of checking the efficiency and uniformity of the furnace work. Therefore the shop inspector Brinells a certain percentage, say 5%, if the previous checks have been carried out and the material processed according to instructions. This rather small percentage of parts tested is permissible only when the collaboration of everyone is secured who in any way is responsible for the making, analyzing, or normalizing of these gears.

Where forgings are to be quenched and tempered (such items as steering arms, spindles and connecting rods) and when the chemical analysis of the steel may vary within the broad S.A.E. specifications, it is necessary to adjust the tempering within a wide range, such as 900 to 1000° F., or such other limits as will give the physicals desired. In such cases, the laboratory, after analysis, will write upon the stock-card "paint yellow," "paint white" or "paint green" as the actual analysis of the particular lot may indicate. A percentage of the rough stock is so identified, and through an understanding between the heat treat and the metallurgical department the recommended tempering range of say 900 to 1000° F. is adhered to as follows: 920° F. for yellow painted forgings, 950° F. for white, and 980° F. for green. However, the heat treat operator should Brinell a percentage of the forgings after the quenching and tempering operations; this will serve as an additional check on the laboratory recommendations, and allow him to make suitable corrections before too much material has been improperly processed.

It might be well to review briefly the forgings that are given physical inspection tests prior to being released to the manufacturing division. The instrument generally used is the Brinell machine, and the percentage of pieces inspected is controlled by subsequent machining operations, service requirements, and the importance of the part in the assembly.

All normalized or annealed parts do not require more than a small percentage test if the various recommended cycles have been properly followed. These would include castings, transmission and differential gears, and a good guess would be that a 5% Brinell inspection would be sufficient as a maximum.

Parts which have been hardened and tempered might require a more varied inspection percentage. In this group we might include steering arms, steering knuckles, connecting rods, pitman arms, axle shafts, and crankshafts which would require in some cases as much as 100% Brinell test, due to the requirements of the part. Again, if the machining operations are difficult, the hardness tolerances might be close, and that would demand closer inspection, but with closely controlled chemistry and accurate heat treating, considerable savings can be effected by reducing the percentage of parts tested.

Carburized Parts

We have not as yet spoken of carburized parts, so it is opportune that the proper procedure be briefly reviewed.

Take piston pins: After analyzing the bar stock it is released to the automatic department and subsequently to the heat treat, where the semi-finished piston pins are packed in a suitable carburizing compound and test pieces of the same material placed in boxes to be used for depth penetration inspection. After these pins have been given a definite heating cycle, the test pieces are removed, hardened, and the case depth examined, sometimes with a Brinell reading glass. If the case depth is correct, the parts are either allowed to cool in the box or are quenched direct, depending on the operations that follow. When finally hardened and drawn, they will be file tested 100% and passed on to

the grinding and lapping operations. Finally a small percentage may be checked further.

Final Inspection of Finished Parts

The greatest of care should be exercised when finished parts are given their final inspection. If, by any chance, an improperly heat treated part should find its way into a final assembly, it would mean a complete disassembly of the unit if it were discovered in the factory. However, if it should slip through and the part were a vital one it might be the means of a serious accident, possibly the loss of a life. (In this respect, I pause to say, the production men have cause for congratulation, for most traffic experts agree that the proportion of automobile accidents due to defective material is negligible.)

It is obvious that the finish of the part is the determining factor in the selection of the type of inspecting instrument, and in order to illustrate this statement let us list a few parts.

First, the Brinell: Such parts as bolts, spring clips, chassis springs and stabilizer bars, which had not been inspected prior to the final machining operation would come within this class.

Second, the Rockwell: In this group would fall some parts that had received previous inspection, such as transmission gears, mainshafts, rear axle gears, flywheel ring gears, bronze bushings and valves.

Next, the scleroscope, which can be used for camshafts, valve stems, piston pins, and other surface hardened parts which must retain their smooth surface.

Finally, the file: This is probably the tool most used in the final inspection of casehardened and cyanided parts, principally because of its speed and accuracy. Parts so tested would include all cyanided parts, camshafts, shackle bolts,

Hardness Inspections on Motor Car Parts

In this list there are several items that are fabricated by outside concerns and received in the finished condition. That, in part, accounts for some of the smaller inspection percentages.

Part Name	Rough or Semi-Finished Inspection		Final Inspection	
	Instrument	Percentage	Instrument	Percentage
Front Axle Assembly				
Axle center	Brinell	100		
Steering arms	Brinell	100		
Steering knuckles	Brinell	100		
King pins			File	100
King pin bushings			File	100
Torque arms	Brinell	20		
Torque arm pins			Brinell	5
Motor and Sub-Assemblies				
Crankshaft	Brinell	100		
Camshaft	Brinell	5	File	100 (each cam)
Connecting rods	Brinell	100		
Piston pins			File	100
Connecting rod bolts			Brinell	10
Valve tappets			Rockwell	100 (by source)
			File	100 (by plant)
			Rockwell	5 (by plant)
			Also Fracture Test	
Valve tappet adjusting screws			File	100
Valves			Rockwell	5
			File	20 (at undercut)
Pistons	Brinell	2		
Studs			Brinell	10
Water pump shafts			File	100
Flywheel ring gears			Brinell	5 (outside item)
			Rockwell	5
Clutch Assembly				
Fingers			File	20
Pins			File	20
Pressure plate	Brinell	2		
Discs			File	2
Transmission				
Mainshafts			File	100
			Rockwell	2
All gears	Brinell	5	Rockwell	100
			File	100
Shifter levers			File	20
Shifter shafts			File	20
Rear Axle Assembly				
Ring gears	Brinell	5	File	100
Pinion	Brinell	5	File	100
Differential				
side gears			File	100
side gear pinions			File	100
pinion shafts			File	100
Drive shafts			Brinell	100
Miscellaneous Chassis Parts				
Chassis springs			Brinell	2
Shackle bolts			File	100
Stabilizer bars			Brinell	5
Spring clips			Brinell	5
Cast iron parts			Brinell	2
Cyanided parts			File	20
Bronze bushings			Rockwell	2

piston pins, gears, king pins and larger parts such as mainshafts.

In the final inspection, the percentage of tests is frequently 100% and very seldom less than 20%.

It is sometimes necessary to use two of these instruments in the final inspection. This is true of the transmission gears, already selected as the specific example. You will recall that after normalizing, 5% of them were Brinell tested. Satisfactory uniformity being disclosed, they were sandblasted and released to the gear department for operations such as drilling, broaching, turning, tooth cutting and burnishing. Finished gears are then sent to the gear hardening department. Hardened and tempered in accordance with heat treat instructions, this gear is now ready for a final physical inspection.

In this case it will consist of the Rockwell machine and a file. A gear tooth is "spotted," that is, polished smooth on its outside diameter. The gear is then placed in a suitable fixture so the prepared surface is square with the conical-shaped diamond brale, the load applied, and Rockwell hardness read. If within the limits it is passed on to the next inspection which consists of file testing a few teeth on the pitch line. If O.K. it is released for final assembly.

The reasons for these tests are as follows:

In the first place, the type of steel requires a 1500° F. quenching temperature, the service requirements demand a cyanide dip at the same temperature, and the tempering was such that it did not affect the thin cyanide film on the teeth. The Rockwell test is, we believe, the nearest approach to a Brinell, and in this case it would give us some idea of the depth of hardness without making too great an indentation. The outside diameter of the tooth was polished to remove the thin cyanide case and any tool marks resulting from the turning operation, and thereby obtain an accurate Rockwell reading. The file test on the pitch line was to ascertain whether the cyanide dip had been well done.

All manufacturers are dependent on some outside source for parts whether semi-finished, finished, or subassemblies. In order to inspect this incoming material properly, a separate unit is maintained, whose duty it is to perform such inspection as is consistent with the requirements of the part. In very rare cases are 100% inspection tests necessary in this department, because suppliers, knowing that rejections mean loss of revenue and possible loss of business, are very careful in their own inspection.

In summing up, it may be useful to tabulate the important parts in the various assemblies, the type of hardness inspection and the percentage inspected in the Hudson Motor Car plant. It is our belief that hardness is a test that indicates service results, and therefore if properly and conscientiously used, will lessen field complaints considerably.

Take a steering spindle: If the heat treat operator carelessly underquenches this part and the inspector, not on the job, passes it, this same spindle in the front axle assembly may be the cause of a very serious accident. If this same part is not properly drawn, the same disastrous results may occur.

Or, consider a connecting rod: If either underquenched or underdrawn, it will break, the result being the complete ruin of the motor.

Looking at the table on page 37 with this in mind, it will be recognized that service requirements were uppermost in mind when the method of test was selected and the percentage inspection fixed.

It all boils down to this: The specifications of material and heat treatment are considered from two angles; first, design; second, service requirements. In order to assure ourselves that the first will be taken care of we specify a material which when processed will require a minimum of attention.

Secondly, the parts that demand the greatest of care in the selection of materials, their heat treatment and final inspection are those that would involve property or physical damage in the event of failure.

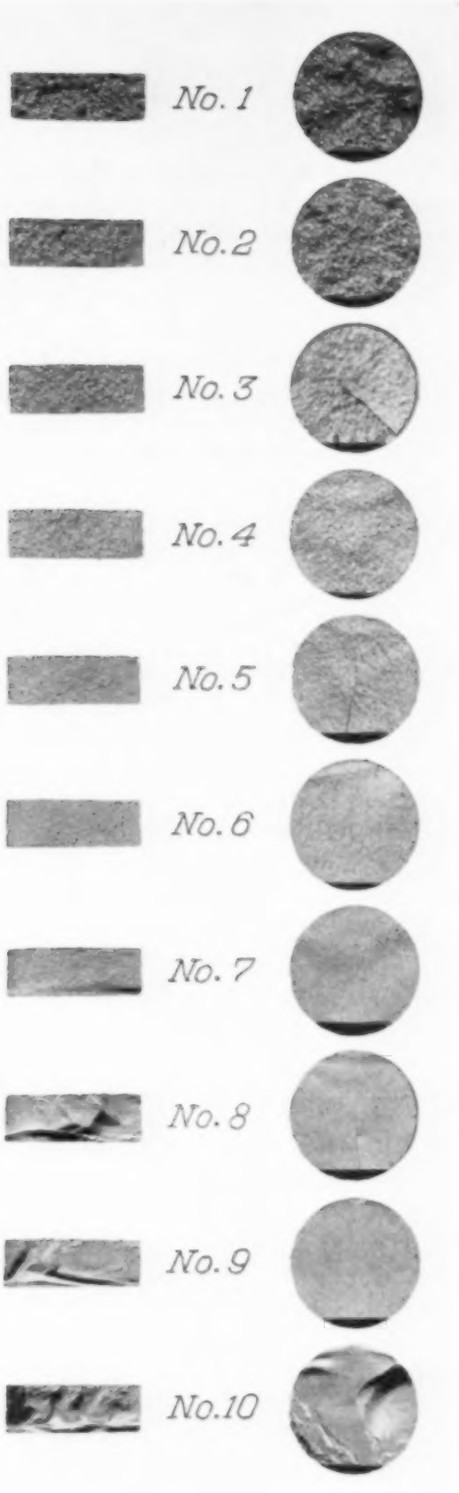
Revealing *the* Austenitic Grain Size *of Steel*

By J. R. Vilella and E. C. Bain

Research Laboratory

United States Steel Corporation

Kearny, N. J.



Standard Fractures

AS A RESULT of the widespread recognition of the significance of austenitic grain size as a factor in steel quality, its determination has become one of the major routine tests made by both steel producer and consumer. Hitherto these estimations have been made mainly upon the steel after carburizing in accord with the McQuaid-Ehn Test; there are now, however, other methods which can be carried out more easily and in a fraction of the time. These will now be described and compared.

In principle, the problem of determining the grain size at heat treating temperature that actually correlates with the behavior of steel is not as simple as in other metals, because one is dealing with austenite, a constituent which is no longer present when the examination is made. Fortunately, however, austenite transforms in such a way as to reveal its former grain boundaries unequivocally. This comes about through three circumstances:

(1) Transformation of austenite to carbide and ferrite begins generally at the grain boundaries, and may be stopped when the transformed material appears as a thin network about the original grains. In hypo-eutectoid

and hyper-eutectoid steel, the first step is the separation of pro-eutectoid ferrite or carbide respectively; in either case, under appropriate conditions, the separated material forms a complete or nearly complete network. In eutectoid steel, in which there is no excess constituent, the moderately rapid transformation to fine pearlite (nodular troostite) also starts at the boundaries and may be stopped at that stage; the rest of the grains are then induced to transform in quite another manner, again forming a contrasting network about the grains.

(2) When martensite, or moderately tempered martensite, is etched with an appropriate reagent, the orientational differences among the parent austenite grains (still sufficiently reflected in the hardened specimen) are revealed, and this enables their size to be estimated.

(3) The fractured surface of a hardened specimen (martensite) discloses the grain size of its parent austenite.

In some respects, the fact that the grain size of austenite is estimated microscopically upon its decomposition products and not upon itself is an advantage, for this circumstance permits the grains to be outlined by constituents which on etching develop great visual contrast with the remainder of the grain.

The McQuaid-Ehn Carburizing Test

It was only natural, when the correlation of austenitic grain size with the behavior of higher carbon, heat treating steels (other than the carburizing grades) was first considered, that the McQuaid-Ehn carburizing test should be utilized to supply the desired information, as this technique was familiar and it had demonstrated its usefulness for casehardening steels. This test, while undoubtedly useful in its original application, is unduly time-consuming and does not always furnish the specific information that may be desired. The extension of this test to all types of low alloy and plain carbon steels not used in the carburized condition carries with it the implication that the grain size developed in a steel after carburizing for 8 hr. at 1700° F. (925° C.) in some way correlates with, or predicts, the properties that the steel will possess after heat treatment at, say, 1450° F. (785° C.) for 30 min. in a non-carburizing atmosphere. In other words, these tacit assumptions are made:

(1) That the introduction of carbon and oxygen during the carburizing period does not alter, in a significant way, the tendency to grain growth behavior characteristic of the steel.

(2) That if steel is fine grained after 8 hr. in the carburizing box at 1700° F. (925° C.) it will also be fine grained when heat treated at lower temperature for equal or shorter times.

(3) That if steel coarsens during this test it may be expected to coarsen when heat treated in practice, even at considerably lower temperature for a shorter period of time.

Refuting the last assumption first, it is scarcely necessary here to marshall the familiar experience of all that there are many steels in which grain growth germinates at a temperature below the 1700° F. carburizing temperature, yet well above that at which it is actually heat treated. Such steels are either coarse grained or "duplexed" (mixed grain size) on the basis of the McQuaid-Ehn carburizing test, yet many of them are uniformly fine grained when heat treated at temperatures as high as 1650° F. and possess all attributes of fine-grained steels.

With respect to the validity of the first two assumptions, consider the following experiment: A section of a steel to which two pounds of aluminum per ton had been added, and analyzing 0.56% C, 0.81% Mn, 0.16% Si, exhibited, after carburizing in the McQuaid-Ehn test, a grain size classed as No. 8 on the A.S.T.M. standard chart. Specimens of the same steel, heat treated in the absence of a carburizing compound for various lengths of time at several temperatures had the following grain sizes:

Temperature	Time at Temp.	Grain Size No.
1425°F.	20 min.	7
	45	7
	180	90%7; 10%3
1525	20	7
	60	75%7; 25%4
	180	75%7; 25%3
	300	25%7; 75%2
1625	20	7
	45	70%7; 30%4
	180	5%7; 95%3

These data show marked grain growth in a shorter time at temperatures below that employed in the McQuaid-Ehn test in a steel which remained definitely finer grained after the carburizing test at 1700° F. (925° C.). They lead us to believe that if the heating to carburizing temperature had been exceedingly slow, the carburized grain size would have been coarse. While the behavior of this particular steel is

not typical of the grade, it serves to demonstrate that none of the assumptions implied in the extension of the McQuaid-Ehn carburizing test to heat-treatable steels can safely be said to be valid in every case.

By way of summary, it appears that the McQuaid-Ehn test falls short of being an ideal universal method for the following reasons:

(1) It fails to disclose the really significant grain size, namely, that established at the heating temperature employed in practice (and responsible for the steel's properties), which is not necessarily that produced at the otherwise irrelevant temperature of 1700° F.

(2) By introducing carbon and oxygen it can only disclose the grain size of the steel as thus possibly modified, and this is frequently not the same as that of the unaltered metal.

(3) The whole test usually requires well in excess of 8 hr. — 12 to 16 hr. or even longer.

Non-Carburizing Methods

Davenport and Bain in their publication "General Relations Between Grain Size and Hardenability and the Normality of Steels" *(Transactions,* ⊜, v. 22, p. 879, 1934) have described three methods by which the austenitic grain size of steel can be revealed without recourse to carburization. The underlying principle is that outlined in the third paragraph, at the very outset of the present article.

These methods possess three distinct advantages: *(a)* There is no danger of modifying the steel by the introduction of carbon and oxygen. *(b)* They may closely simulate any heat treatment, especially as to the significant factors which are temperature, time at temperature, and (possibly) rate of heating. *(c)* A short time only is required to complete a determination of the grain size.

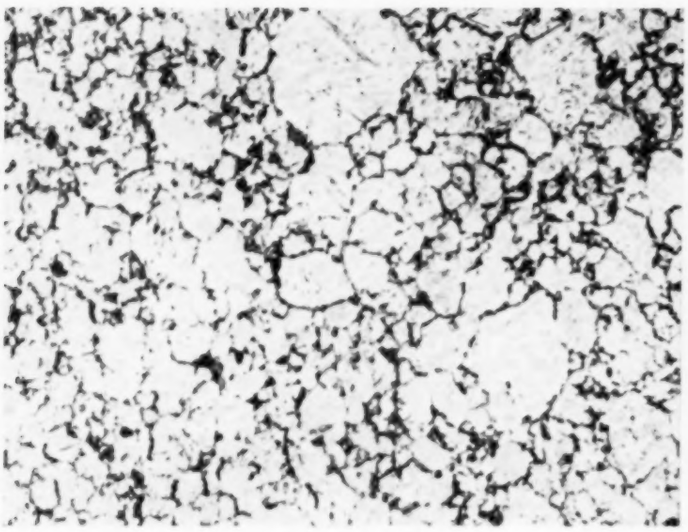
The only criticisms advanced against these methods are that they occasionally fail to delineate the individual grains in the very finest structures with clarity sufficient to estimate the grain size to an accuracy of a single A.S.T.M. number; and second, they do not yield supplementary information concerning the "normality" or "abnormality" of the steel.

With respect to the method proposed in the above-mentioned publication for revealing the grain size of hyper-eutectoid steel, little need be said. It consists simply of air cooling a convenient specimen from any desired temperature above the A_{cm}; this is generally sufficient to produce a network of pro-eutectoid carbide which outlines the austenite grains unmistakably. In case it is desired to know something about the "normality" of the steel, the sample may be cooled slowly in the furnace. In some instances (as when the steel contains considerable alloy, or is only slightly hyper-eutectoid) it is sometimes preferable to cool the sample slowly to just above the A_1 and hold it there for several minutes to form the network of intergranular carbide.

The procedure for eutectoid steel as described by Davenport and Bain is as follows: When the material on hand is plain carbon steel and has a thickness of about one inch, the specimen is heated to the desired temperature and quenched in brine. Unless the metal is exceptionally deep hardening, the interior of the quenched sample will consist of fine pearlite (nodular troostite), the outside layer will be martensite, and at some intermediate region the structure will comprise a light etching martensitic background and just sufficient fine pearlite at grain boundaries to delineate them clearly.

If the material to be tested is of small cross section, or very deep hardening, it is necessary to quench differently, by what may be called "gradient quenching." A longer specimen — which in carbon steel may be only 1.5 in. long by 0.25 in. or less in thickness — after heating to the desired temperature, is cooled by quenching one end in brine. Only about 0.5 in. needs to be immersed while the rest of the specimen cools in air. In this way a continuous series of cooling rates is produced; the austenite transforms to martensite in the portion that was brine quenched, and to increasing proportions of fine pearlite in the region just above. Here again, it is always possible to find, between the fully martensitic and fully pearlitic regions, a section of the specimen in which the austenitic grains are outlined by a network of fine pearlite.

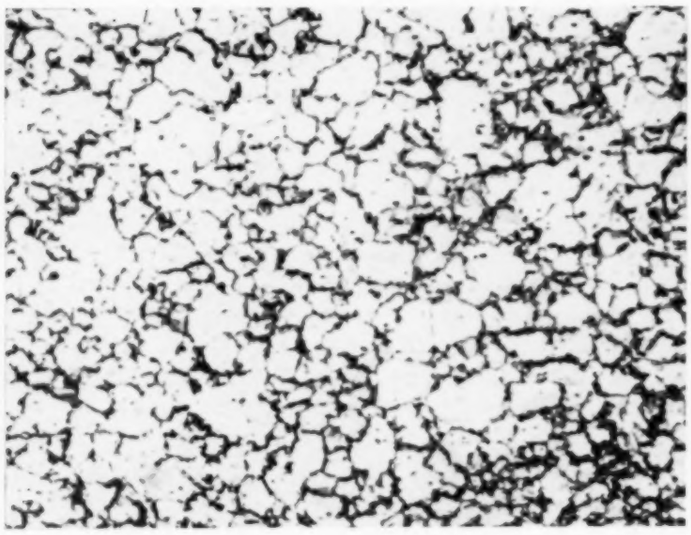
A method of handling *hypo-eutectoid* steels, now to be described for the first time, differs in some respects from the procedure originally described by Davenport and Bain. By applying to hypo-eutectoid steels (either carbon or low alloy steels) the technique of gradient quenching outlined above, it is possible, in a single specimen and with one procedure, to reveal grain size in several ways in a wider range of compositions. The specimen, at least 1.5 in. long and about 0.10 to 0.25 in. thick, is heated to the desired temperature and approximately 0.5 in. of its length is immersed in brine solu-

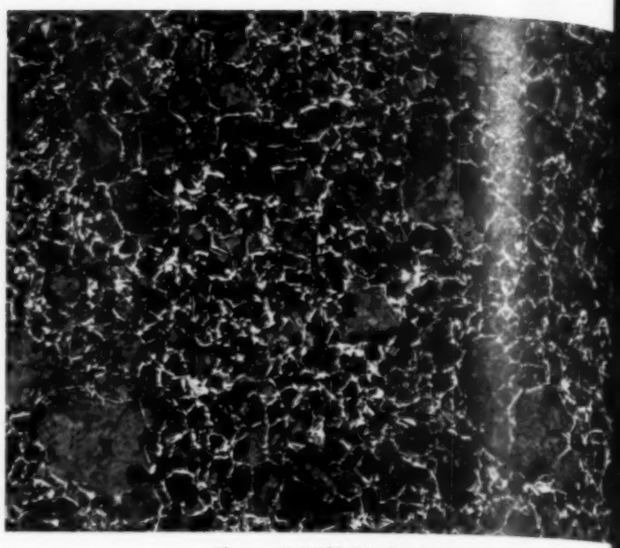


Above: 0.20% Carbon Steel

Austenite Grains Outlined by Network of Fine Pearlite (Nodular Troostite); 100X

Below: 0.50% Carbon Steel

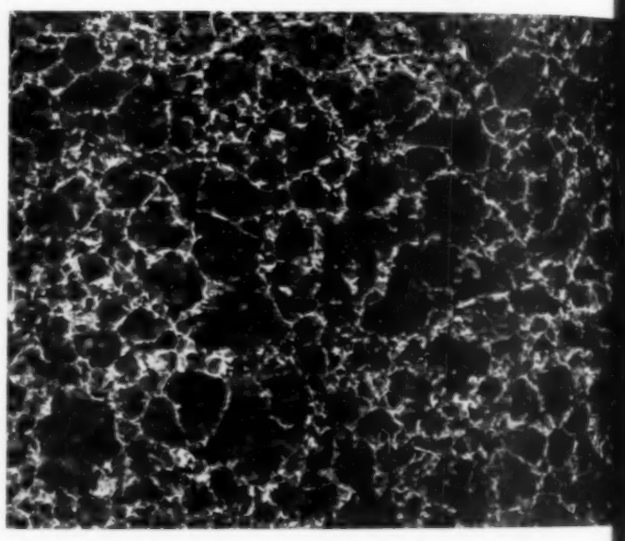




Above: 0.20% Carbon Steel

Austenite Grains Outlined by Network of Free Ferrite; 100X

Below: 0.50% Carbon Steel



tion while the rest of the specimen cools in the air above. Thicker sections may be necessary for alloy steels. After the portion cooling in the air above the brine is no longer red hot, the entire specimen may, without impairment, be plunged in the quenching medium. On examining a longitudinal section covering the gradient zone it will be found that the prior austenitic grains stand revealed in one place or another, either by a network of fine pearlite or by a network of pro-eutectoid ferrite.

Typical results obtained upon specimens containing 0.20 and 0.50% carbon are illustrated by figures on this page. Attention is called to the distinctness of the network obtained in these un-carburized steels, one of them containing as low as 0.20% carbon. These micrographs might easily be mistaken for McQuaid-Ehn test photographs of carburized steels, the light colored ones resembling the hyper-eutectoid zone as etched with sodium picrate, and the dark colored ones the same field etched with ordinary nitric acid in alcohol. Actually they show the true austenitic grain size of single specimens of hypo-eutectoid steel with a network etching either dark or light depending upon the position in the "gradient-quenched" specimen. The etchant is a 4% alcoholic picric acid solution.

Gradient quenching has the advantage of automatically providing two zones in the specimen where the grains are outlined by a continuous network, either of ferrite or of fine nodular pearlite, and a third, or martensitic zone, to be treated as described below. It is therefore unnecessary to pre-determine an optimum cooling rate or to hold at any intermediate temperature to develop the desired network; somewhere in the specimen the optimum

rate will have been reached automatically.

Steels containing in the vicinity of 0.70% carbon exhibit a network of fine nodular pearlite when gradient-quenched, but since they are so nearly eutectoid in composition, the separation of a continuous ferrite network is not to be expected even in the slowest cooling part of the specimen, unless it be inconveniently large. If, for any reason, a ferrite network is desired, it may be obtained in another specimen by very slow cooling. The same applies to the higher alloy, hypo-eutectoid steels.

Martensite Etching Method

It is often desirable to know the austenitic grain size of steels already quenched, or quenched and tempered. Hitherto this has not been practicable, for the ordinary etching methods disclose only the needle structure of martensite. Likewise there has been no satisfactory way of revealing austenitic grain size of air hardening steels except by very slow cooling.

There has long existed a strong presumption that the texture of the fracture of fully hardened (martensitic) steels, as estimated by a trained eye, gives a measure of the coarseness or fineness of the prior austenitic structure. B. F. Shepherd, in his paper "*P-F* Characteristics of Steel" (*Transactions*, ASST, v. 22, p. 979, 1934) strengthened this presumption by demonstrating that the fineness or coarseness of the texture observed in the fracture of martensitic steels correlates with the heating temperature and hardenability of the steel in precisely the same way as has been shown by the present authors for the austenitic grain size measured microscopically. This similarity emphasizes the thought that when austenite is converted to martensite, the same grain size (or at least a grain orientation closely related to that prevailing in the austenite) is transmitted to the martensitic structure — in other words, the facets observed in a martensitic fracture are derived directly from the original austenitic grains. If this reasoning is valid, an etching reagent sensitive enough to differentiate among grains differently oriented should be discoverable.

With this in mind, a search was started for such a reagent. Thus far, the best results have been obtained with 1 gram picric acid, and 5 cc. concentrated hydrochloric acid, in 95 cc. ethyl alcohol. Etching is by immersion at room temperature and generally requires from 5 to 15 sec. Two or more slight repolishings (consuming about one minute each) followed by re-etchings usually help to develop the structure clearly. While this reagent is capable of bringing out the austenitic grains in fully hardened and untempered steels, it acts best when the steel is slightly tempered; 15 min. at 400 to 600° F. (200 to 300° C.) is generally sufficient.

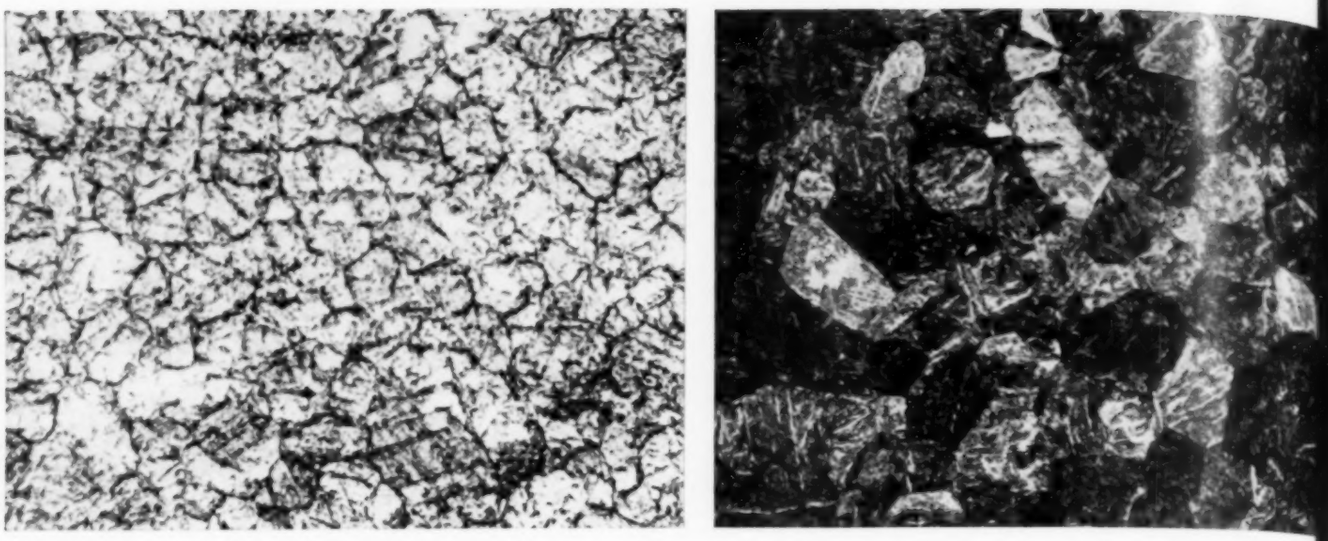
This reagent satisfactorily discloses the prior grains of austenite in plain carbon steels (0.40 to 0.95% C) and low alloy steels containing chromium, molybdenum, manganese, tungsten, or nickel, as well as various combinations of these elements. It has also proved its ability to disclose the grain size of steels quenched from a wide range of temperatures above the critical range. Typical results are illustrated in two figures on top page 44.

The photomicrographs illustrating this article indicate that it is possible to approach, by this etching method, the sharp and unmistakable definition of the grains generally obtained by the McQuaid-Ehn test or by the non-carburizing methods. Like the other non-carburizing methods, it possesses the merit of revealing the grains established at any temperature without altering the characteristics of the metal by the introduction of carbon and oxygen. It can be carried out in a very short time, requiring only the brief heating period employed in regular practice followed by quenching, or quenching and tempering. At its present stage of development this method is properly used:

1. As a very rapid method to accompany the examination of fractures, particularly in alloy steels of the air hardening class.
2. To reveal the size of the grains in steels already hardened, or hardened and tempered.
3. To aid in the examination of eutectoid steels when Davenport and Bain's method fails to outline the grains satisfactorily.

Austenitic Grain Size From Fracture

It has been mentioned that a correlation of the properties of steel had been made with the coarseness or fineness of its fracture when in the martensitic (hardened) condition. As early as 1926 this relationship was used as a quantitative measure of certain aspects of steel quality at the Uddeholm Steel Works in Sweden. At first only five recognized grades of fracture were employed but later the work was extended through the supervision of Jernkontoret, the Swedish Iron Masters' Association. In 1927 a ten-step scale was recommended as a suitable



Austenite Grains in Untempered Martensite (Left) and in Slightly Tempered Martensite (Right) as Revealed by Picric-Hydrochloric Acid in Alcohol; 100X

measure of tool steel quality and sets of standard fractures in 22-mm. square bars were made up under the direction of Ragnar Arpi. These bars covered the full range of coarseness and fineness usually encountered, by steps which to the eye appear evenly spaced. That they are, in fact, evenly spaced will be shown below.

In America, Shepherd employed two criteria jointly, namely, hardenability and appearance of fracture, as a measure of the probable suitability of steels for certain purposes. He prepared a reference set of graded fractures in which the entire cross-section was hardened. In his practice, to gain an adequate impression of different bars of steel he generally hardened specimens of definite section from four heating temperatures, 1450, 1500, 1550, and 1600° F., and secured thereby a pattern for the coarsening of the steel at increasing temperatures. The fracture was compared with his reference set, (which proved to be very similar to the Swedish standards). The latest standard fractures, hardened throughout in both cases, of Shepherd and Jernkontoret, numbered serially 1 to 10, are shown full size in the half tone at the head of this article. Careful comparisons show that the two scales may be regarded as identical for most practical purposes.

It will by this time have become almost obvious that there is a marked degree of parallelism, more than purely fortuitous, between coarseness of fracture and the grain size of the austenite which existed in the specimen before it was quenched and broken. This relationship proves to be closer than was at first supposed, for, as is clearly shown in the micro on page 45, the path of the fracture, when martensite breaks, follows the boundaries of the prior austenitic grains.

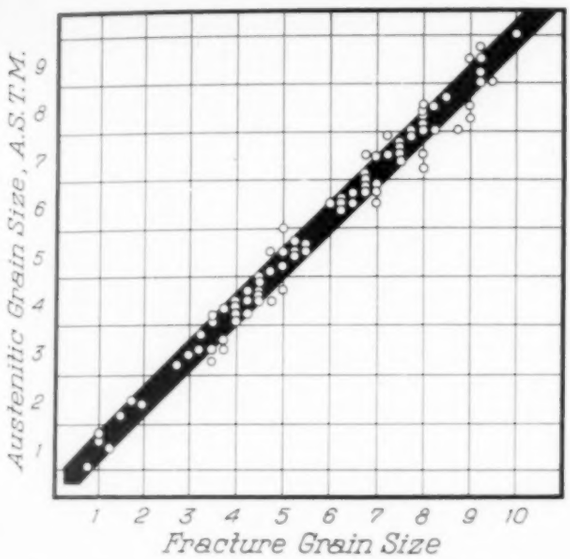
As shown by the graph on the same page, the estimation of a great many fractures shows a linear relationship between the Shepherd or Jernkontoret fracture numbers and the austenitic grain size (as determined by the non-carburizing methods discussed above) responsible for the fracture appearance. It should be borne in mind that the eye is able to arrive at a mean value of the coarseness of a fracture, and that for correlating fracture number with austenitic grain size the mean value of the latter should be used. Thus if a specimen were accurately rated 65% No. 6 and 35% No. 4 (A.S.T.M. scale), then its mean grain size would be about 5.3 and it would exhibit a grain size on the fracture scale between 5 and 6.

There is one interesting fact about estimating prior austenitic grain size by fracture: The eye is more *sensitive* to slight changes in fracture appearance than is the corresponding estimation on the microscope of mean grain size. Experienced observers of fractures will agree within one-half, and often within one-quarter, of a single step in the fracture series. There is probably no urgent need even for as many steps as exist in either the A.S.T.M. grain size rating or the fracture rating, since the properties that are reflected by grain size are not greatly modified by small changes.

A word should be said about the fracture appearance of specimens having a non-uniform or mixed grain size. Actually there will be large facets mixed with the fine on the fractured surface, but the eye does not at once recognize this unless the fracture is fairly coarse; instead,

undue influence is exerted by the few coarse facets. Nevertheless an experienced observer can identify mixed grain size very reliably from fracture appearance with a little practice.

In a very few anomalous cases considerable experience may be necessary to estimate actual grain size from fracture. The most notable of these is the case of an austenite which at elevated temperature coarsens abnormally, having been inhibited until the high temperature is reached. The surface of each grain is then slightly matte — not brilliant — suggesting a fine



Comparison of Jernkontoret and Shepherd Scales of Fracture Grain Size Indicated Them to Be Equivalent Within the Limits of the Black Band. Circles in above diagram correlate these fracture grain sizes and the austenitic grain size of individual samples as determined by the new microscopic methods

grain size, while the large grain size is also apparent from a faint glimpse of large facets.

It is easy and practical to combine a hardenability test with an evaluation of grain size by fracture, as has been done by Shepherd. A standard size of the test specimen must be adopted and rigidly maintained, and the fracture examined at the rim, fully hardened or dominantly martensitic. The depth of this rim can be measured (by 64ths of an inch in Shepherd's technique) after it is rendered visible by etching. Shepherd recommends that eight numbers be reported in order to classify certain grades of carbon steel as to their suitability for hardened parts. The first four numbers are depths of hardened zone in 64ths of an inch after quenching from 1450, 1500, 1550, and 1600° F. respectively, while the second four numbers are the fracture numbers of the respective hardened zones. It should be stressed that the information secured by this *P-F* test (*P* representing penetration of hardened structure and *F* the fracture rating) goes far toward giving a full account of the nature of carbon steel. "Normality" or microscopically observed grain size is often superfluous. Obviously alloy steels may harden throughout such large sections that the hardenability feature (*P* values) is inapplicable; the fracture rating is still valid, however.

The most rapid examination of a steel for significant grain size characteristics consists of first rating the fracture; if the size is uniform the A.S.T.M. grain size may be reported at once, but if the fracture shows the probability of mixed grain size it may be polished, etched and rated microscopically by the standard chart.

In summary, there are therefore at least three methods, which do not involve carburization and possible alteration of the steel, for the estimation of true austenitic grain size. These methods are short and direct, and enable the metallurgist to measure the grain size established at any heat treating temperature, which in large part controls the final properties of the heat treated article.

Intergranular Fracture in Martensite. Hardened sample broken by impact, both ends of fracture re-fitted, polished and etched with new martensite reagent. 100 X. Fracture under slowly applied stress is also intergranular, an evident reason for the close correspondence between estimates of fractured surface and measurements of austenitic grain size with a microscope

Sheet Metal

appraised by

Hardness, Ductility

and

Grain Size

By Ernest E. Thum

Editor, Metal Progress

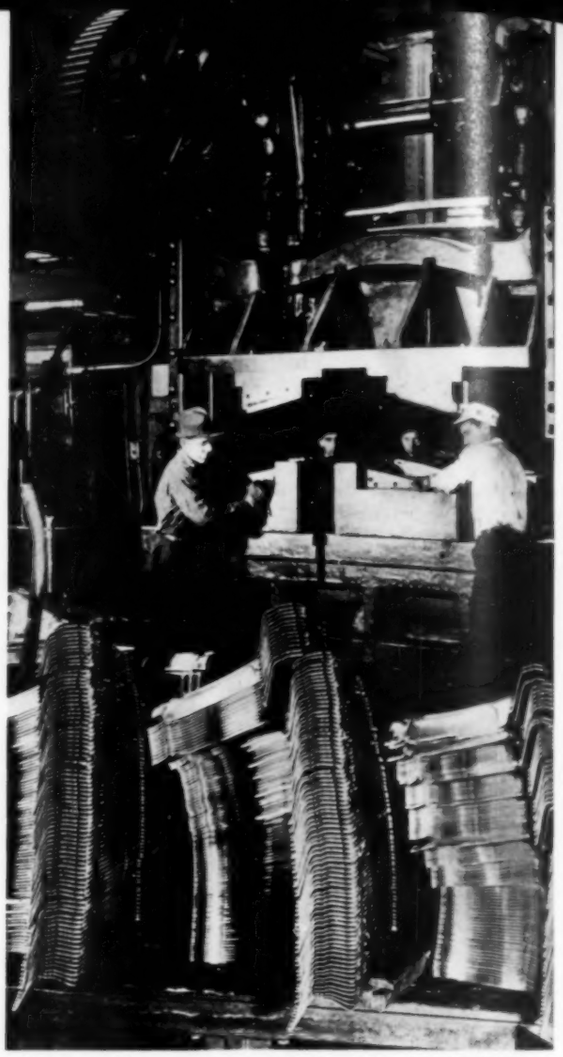


Photo by Margaret Bourke-White for Edward G. Budd Mfg. Co.

PRIOR to the writing of specifications for sheet high brass by the American Society for Testing Materials, a careful study was made, by leading producers and consumers, of all available methods for testing sheet nonferrous metal. As summarized by John R. Townsend of Bell Telephone Laboratories, "Whereas the Rockwell hardness test was adopted as a preliminary inspection test, the tension test was considered the basic test upon which the acceptance and the rejection of the material was based. Sheet brass, for example, is used for a variety of purposes and here the essential characteristics that are important are strength, hardness, wear resistance, spring properties, ductility and corrosion resistance. Experience has shown that if the chemical composition limits are met, either the hardness or tension test limits will adequately control wear, corrosion resistance, ductility, formability and a host of machining operations that must be performed upon the material. It is incompatible that sheet brass meeting the chemical, hardness, and tension tests would show any high degree of variability in the other properties."

It has been held by competent testing engineers that sheet steel (even deep drawing stock) of good surface appearance can be adequately controlled by chemical composition, heat treatment, grain size, hardness, tensile strength and elongation. Round-table discussions and a number of technical papers both in *Transactions* ⊕ and *Proceedings* A.S.T.M. have, however, developed no unanimity of opinion as to the use of either the hardness test or the tension test for judging the suitability of sheet steel for various purposes. It is recognized, of course, that *any* careful program of testing and the placing of close acceptance limits will tend to improve the control of all steps in a manufacturing process, and thus contribute to the successful use of metal, even though by quite indirect means.

Hardness (stiffness) should be measured by the indentation test most suitable to the gage of metal. The harder the metal the more clearance is necessary between punch and die. Also the blank-holder pressure will have to be adjusted as the metal becomes harder. Thus the press operator is helped by advance knowledge

of the hardness of each lot he has to run, and the optimum range of hardness will be determined by experience. When thus determined for any given job, tests of each shipment will indicate its suitability for the use intended. Either because of this, or because of its convenience, hardness is widely used to check various stages in production of sheet steel and cold-rolled strip, where the analysis of the steel, the way it is finished, the rolling temperatures and annealing temperatures are under control.

The problem of getting the correct hardness of thin sheets has not yet been solved. Usually Rockwell B scale readings are made on single sheets down to a limiting thickness and on thinner gages using more than one thickness. Reid L. Kenyon has determined that this limiting thickness depends on hardness, as follows:

Hardness	*Thickness*
B-20	0.040 in.
B-40	0.036 in.
B-60	0.032 in.
B-80	0.027 in.
B-100	0.023 in.

This is the thickest specimen showing a bulge on the underside, and the thinnest one that gives accurate hardness tests corresponding to deviations of two Rockwell numbers from the hardness of thicker pieces (about the limit of accuracy of plant inspection). One consumer has checked this in practice, successfully controlling large tonnages of high carbon, cold-rolled strip 0.025 in. thick in severe forming operations between B-75 and B-82.

Whenever two or more sheets of smaller thickness are piled before test, this fact should be noted on the report for whatever interpretation the reader cares to make. Whether the standard anvil or the diamond anvil is used should also be noted. It is important that the shear-burr be removed before piling and the pieces be clamped together so they will not shift between successive tests; otherwise results will be discordant by as much as 10 to 15 points.

Even though the results on smaller thicknesses are not comparable to the results obtained on the heavier gages, they are in many instances entirely applicable to the purpose at hand. For a given thickness of material in about the same hardness range, the "anvil effect" will be reasonably constant. Of course, hardness is a somewhat arbitrary convention; the danger is that some consumer may specify a Rockwell hardness on thin metal without making allowance for the fact that the result will be affected by the so-called anvil effect, and will not indicate the same condition of the metal as an identical test on heavier gage metal.

Many manufacturers and consumers have come to the conclusion that no one test is able to indicate ductility of sheet steel so as to be correlated with workability in the press shop, and have adopted combination tests which bear a useful relation to their specific problems. As one leading metallurgist put it: "For years it has been my confident belief that various laboratory tests can tell us more certainly the quality of steel sheets for automotive stampings than the usual report from the press operator, whose results are varied so greatly by tightening one screw and loosening another. After a sufficient length of time the press operator can try all the variations and eventually get the correct answer. In the end he will agree with our laboratory tests. Our experience is that we can tell how steel sheets will work in the stamp press by combined use of the Rockwell and cupping tests, and buy our sheets on such a specification."

In order to develop facts concerning present practice a third round-table discussion on ductility testing of thin sheet metals was held in Detroit during the 1935 annual meeting of the American Society for Testing Materials. Mimeograph notes of this meeting are now available for summary. The meeting was sponsored jointly by the Section on Testing Thin Sheet Metals (C. H. Marshall, chairman) and the Section on Bend Tests for Ductility (A. B. Kinzel, chairman), and the details in arranging the meeting and preparating the summary were made by A. L. Davis and C. H. Greenall.

It developed that the Erichsen and the Olsen cup tests were regarded by steel producers as supplemental to hardness tests, and normally made only when specified by the purchaser. Tests have been carried out by the section of Committee E-1 on cup testing, and indicate reasonably concordant results from a given machine and operator. Where specifications are to be operative and if values obtained by producer must check with retests by the consumer, it is desirable to exchange samples and determine the coordination constant for the machines in the two laboratories. It is important to reduce all samples for cup test to an equality of surface condition by oiling, if need be, and wiping off to leave a slight film.

In many instances the test is used principally as a rapid method of determining directional properties and grain size. Another view is that

cup tests yield a variety of information otherwise requiring several tests. Thus the position of break indicates whether failure is liable to result from cracking (if parallel to the direction of rolling) or from tension (if across the direction of rolling). The pressure to draw a cup of unit depth also measures the tensile strength or Rockwell hardness, and the smoothness of the cup indicates grain size.

The theoretical objection to the standard tensile test as a measure of the deep drawing quality of sheet metal is that the metal has two degrees of freedom in the tensile test (width and thickness) and only one (thickness) in the drawing operation. Thus, quite different conditions exist, and the restraint of lateral movement in the drawing operation will affect the depth of draw before rupture. The lower the compression yield point, the more favorable it is to deep drawing, other properties being unchanged. The greater the compression yield point the higher the tensile stress, and the greater the pressure required on the drawing punch.

The effect of simultaneous stresses along different axes can be illustrated by tests on tubes in a tensile testing machine, exposed to either tension or compression while under internal pressure. The apparent ductility of the tubes is profoundly affected by the tension or compression. With a certain amount of tension, they will rupture without appreciable reduction of area. With suitable compression great expansion can be produced — even to complete flattening to the shape of a cymbal.

Some work had been done on Sachs' "wedge-draw test" where a tension coupon with one wedge-shaped end is mounted in a testing machine. The fixture at the wedge-shaped end is a die and the tension forces either pull the spreading end through or break the specimen in the parallel portion. Friction along the edges of the wedge and the tendency for the metal to thicken up more at the edges than near the center during the draw, introduce serious difficulties that have not been overcome. Conceivably the use of roll dies with grooves suited to a test specimen not greatly wider than its thickness might solve these difficulties.

In a leading brass mill the Erichsen cupping test is being used, not primarily for the sake of getting the depth of cup, but to note very quickly the size of the grain as indicated by the appearance of the apex of the cup. This is a quite satisfactory method. In non-ferrous alloys there are a number of correlated variables affecting the performance of sheet metal in a given service, particularly the thickness of the sheet, the anneal or grain size of the metal, the alloy, and the temper due to cold rolling after the anneal. In a study of each alloy, all of those variables must be taken into account. Such studies are made in the laboratory, but in the mill the cup test is used to very good advantage as a rapid test for grain, or surface texture, of the apex of the cup.

The tensile test and chemical composition are used to control sheet aluminum and its alloys. When the Erichsen ductility testing machine is used, little attention is paid to the depth of the cup; it is simply a standard method for deforming metals to determine, by visual examination, the size of the grains; the tensile results check the temper or degree of annealing. The thinner the material, the less reliable the percentage elongation in the tensile test becomes as a criterion of the workability of the metal; the yield strength tells better whether or not the annealing has been done properly, and gives a little more accurate check on whether the material will perform satisfactorily when subjected to drawing operations than does the elongation or the cupping test.

Sheet zinc is affected in its mechanical properties by the rate of loading. For this reason, the most useful tests have been those which apply the stress at a rate similar to that which occurs in commercial drawing and forming operations rather than the tensile test which is carried out at a comparatively slow rate of deformation.

The A. S. T. M. standard specifications for rolled zinc include the dynamic ductility test, which attempts to reproduce practical rates of deformation. A series of cups of increasing depths are pressed into a test strip in a power press operating at 90 strokes per min. and the depth noted "where the drawing of the bottom of the cup has just caused 'necking' of the surface prior to rupture."

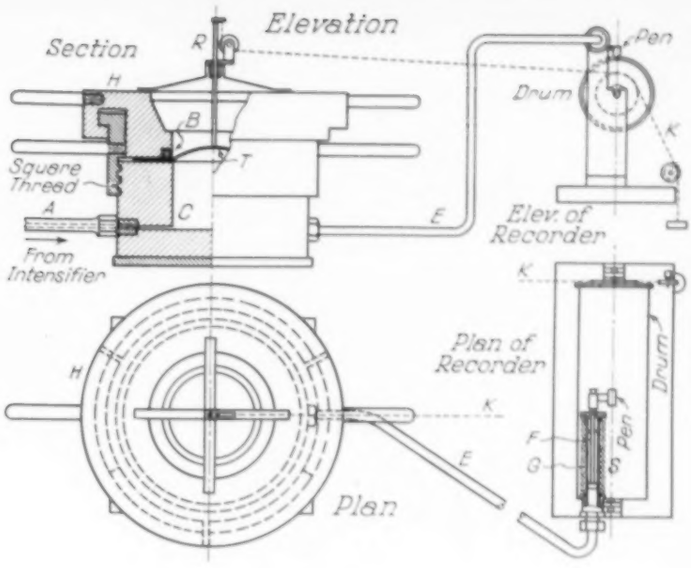
This test is deficient in that it stretches rather than flows the metal and practical experience does not indicate a satisfactorily close correlation between this test and the performance of strip zinc in such drawing operations as the drawing of dry battery shells. Consequently, metallurgists in the zinc industry are leaning towards the use of commercial cupping tools in a commercial drawing press.

For control work, it is found that a given composition of zinc *(Continued on page 92)*

Drawability of Sheet Steel

By H. J. Gough

Condensed from 1935 Report, National Physical Laboratory



DURING the year past the research of the National Physical Laboratory into tests for materials used in cold pressing operations, and in particular the work on the fluid pressure cupping test, was discussed before several societies.

The most important part of the work was the experimental examination of the fluid pressure test, in order to determine whether it was likely to be useful in discriminating between materials which were satisfactory and unsatisfactory in regard to deep drawing properties. The materials used comprised miscellaneous commercial sheet metals from the laboratory stock, materials obtained from industrial sources in view of their known performance in practical cold pressing operations, and a series of representative non-ferrous sheet metals. The machine at first available for the oil pressure tests was a Guillery machine arranged for making tests on the lines originally suggested by Jovignot. In this machine the sample under test is clamped between two annular dies and oil pressure is applied to one side of the sheet. The sample deforms into a spherical dome, and the pressure is increased until fracture occurs; the maximum oil pressure and height of the dome are recorded. The ductility of the test sample is expressed by a "cupping coefficient," equivalent to the increase in surface area of the sample per unit area.

A large proportion of the available samples could not be tested in this machine, owing to the maximum permissible oil pressure being about 2000 psi. In order to carry out tests on the thicker materials available, the oil pressure cupping machine shown in the figure was designed and constructed for a maximum working pressure of 11,000 psi.; an autographic recorder was arranged to give a continuous record of the height of the dome or cup against the applied pressure throughout each test. The test piece, T, is firmly clamped between the top face of the pressure chamber C and a hard steel die B, by screwing down the head H. As the head has to be removed each time the test sample is renewed, it is made in two parts connected by a bayonet fitting. The pressure chamber C is filled with oil, to which pressure is applied through the pipe A, leading to an intensifier. This pressure is transmitted to the recording apparatus through the pipe E; increase in pressure moves the recording pen along the drum on which a chart is fixed, while increase of the height of the dome of the test sample causes the drum to revolve. The recording pen is fixed to the end of a small plunger F, and when pressure is transmitted to the cylinder G, this plunger is pushed along the cylinder against the resistance of a calibrated spring S. A light rod R, guided vertically, rests on the center of the test piece; increase in the height of the spherical dome of the test piece rotates the drum D by means of the rod R and the cord K.

Analysis of the results of the investigation showed that the cupping coefficient, while indicating marked differences in ductility of various metals, was of no real value in discriminating between somewhat similar materials which were known to behave satisfactorily and unsatisfactorily, respectively, in practical cold pressing operations. It was found, however, that the calculated bursting stress in the oil pressure cupping test, obtained by means of the ordinary formula for the strength of thin spherical shells, agreed in many cases with the ultimate stress obtained in an ordinary tensile test. A most interesting feature of the results emerges from the diagrams connecting height of dome with oil pressure obtained with the autographic recording apparatus. A number of these diagrams were replotted as stress-superficial strain curves, and with certain samples of mild steel and stainless steel, differences in practical cold pressing work were clearly reflected in the complete stress-strain curves.

It cannot be stated, from the general results of the investigation, that complete stress-strain curves from oil pressure tests always discriminate between satisfactory and unsatisfactory materials; nevertheless, it is concluded that valuable information with regard to the suitability of a metal for cold pressing can be obtained from these curves, since they provide real knowledge of those plastic distortion properties of a metal which are so directly involved in cold pressing operations.

A Bend Test

for

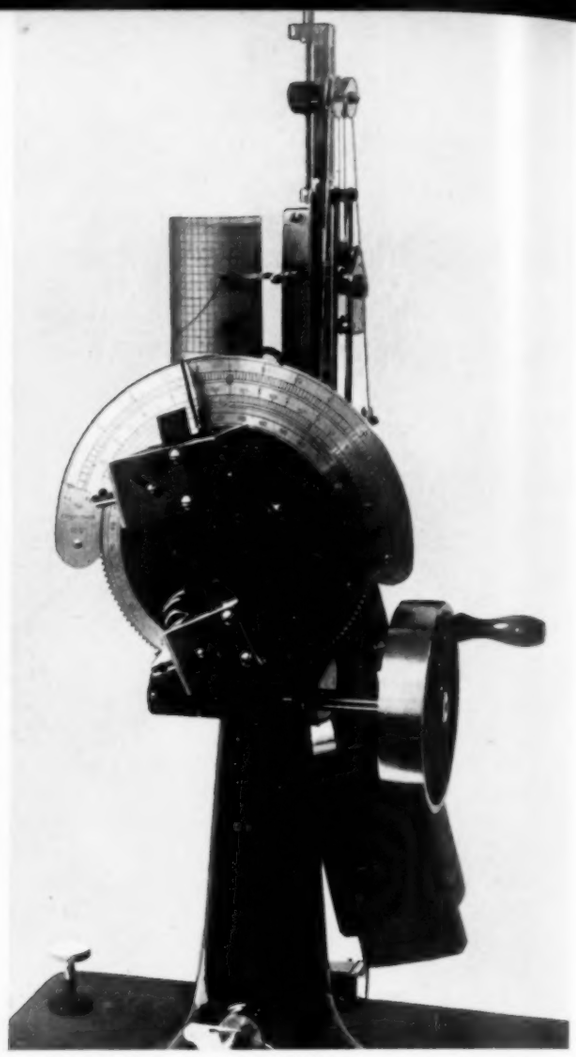
Tinplate

By C. C. Willits

Metallurgical Engineer

Continental Can Co.

Canonsburg, Pa.



PRODUCTION of tin cans and containers, like almost any other item you can think of made of metal, has been refined to closer and closer limits. This tightening up of specifications has been continuous over several years. A major problem facing the technologists in the can companies and steel mills has therefore been the question of how to measure quantitatively the required physical properties of tinplate, the basic material. It is most desirable that some tests be devised that can be performed at the mill and thus avoid the shipment of unsatisfactory material.

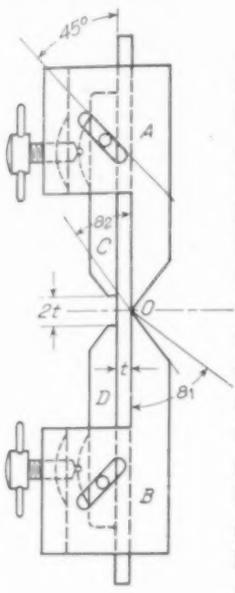
Unfortunately, tinplate, especially the lighter gages, does not lend itself readily or reliably to methods of determining physical properties suitable for heavier sheets and plate (and it is no secret that even the so-called deep drawing stock cannot yet be accurately appraised by laboratory tests). While there are several methods of testing tinplate now employed by the industry to guide them, none of them, either singly or jointly, fulfill the requirements; too much remains to be determined under actual operating conditions at the factory.

After several years' contact with this problem the present writer came to the conclusion that data of the greatest practical value would be secured from that testing machine that would come nearest to subjecting samples to strains and deformations similar to those to which thin plate is subjected in commercial operations, and properly indicate the nature and the magnitude of those strains, their effect, and the effect of the deformation on the test specimen. The machine that eventually met these requirements most nearly was a bending machine designed to test wood veneer and cardboard. It is a German machine designed by Martin Naumann along principles laid down in 1915 by Professor Kirchner, an authority in the paper industry. In this testing machine specimens of a standard width and length are bent, primarily under tension, singly or repeatedly through an angle of 90°, a stress-strain curve being automatically drawn, if desired.

It soon became evident that this machine had very interesting possibilities. Because ours was its first application to the testing of metal plate, there were no data available to assist in

establishing standards; consequently, it was necessary to work backwards, as it were. In due course of time good, fair and poor tinplates of all gages, makes, and treatments were tested and the results carefully studied. Once this procedure was well under way and sufficient data had been collected and correlated for any one gage, it was found that the suitability of a lot of tinplate for a stipulated purpose could be quickly and quite accurately determined.

Sketch of Clamp so Arranged That Bending Produces Nothing but Stretching in Test Piece



A front view of the machine is shown at the head of this article. It is neatly and well built, about 30 in. high. Specimens of tinplate, 2 in. wide by about 4 in. long, are gripped in clamps on the face of the dial. At the beginning these clamps and the specimen are vertical; their construction may be visualized with the additional aid of the adjoining sketch. Clamp *A* is fixed to the face of the upper sector which in turn is attached to a shaft extending backward through the standard (axis at *O*) and keyed to a pendulum at the rear. Clamp *B* is fixed to the face of the lower sector, also pivoted about the same center *O*, but having gear teeth on its edge meshing with a hand-driven worm just below.

Clamps *C* and *D* are movable so as to accommodate specimens of different thickness, and so governed by pins and 45° slots that the end clearances are always equal to twice the thickness of the specimen. The other clamps *A* and *B* have sharp ends closely abutting at the center of rotation of both sectors, so all deformation in the specimen as it bends is of a stretching nature and the bending radius is always equal to the thickness of the specimen.

After the specimen of tinplate is fixed in the clamps, edge-on to the sectors, the hand wheel is turned slowly, moving the lower pair of clamps counterclockwise. The stiffness of the strip under test tends to turn the upper pair of clamps through a similar angle, but this is opposed by the action of gravity on the pendulum, keyed to the upper sector. The deflection of the pendulum is therefore a measure of the torque required to bend the specimen. This deflection is indicated by a pointer operating in front of a semi-circular scaleplate on the front of the machine.

The actual angle of bend of the specimen will depend on the relative positions of clamps *A* and *B*. This angle is indicated on a circular scaleplate, also on the front of the machine. By an arrangement of flexible wire cable and pulleys operating a pen and a drum, both torque and angle are recorded in the form of a curve — the torque horizontally, by virtue of the rotary movement of the drum, and the angle vertically, by up and down movement of the pen.

While the pendulum and the clamps may be operated through an arc in either direction, most of the more important information this machine will furnish about tinplate is obtained during counterclockwise motion between bend angles of 0° and 90°.

Results on Tinplate

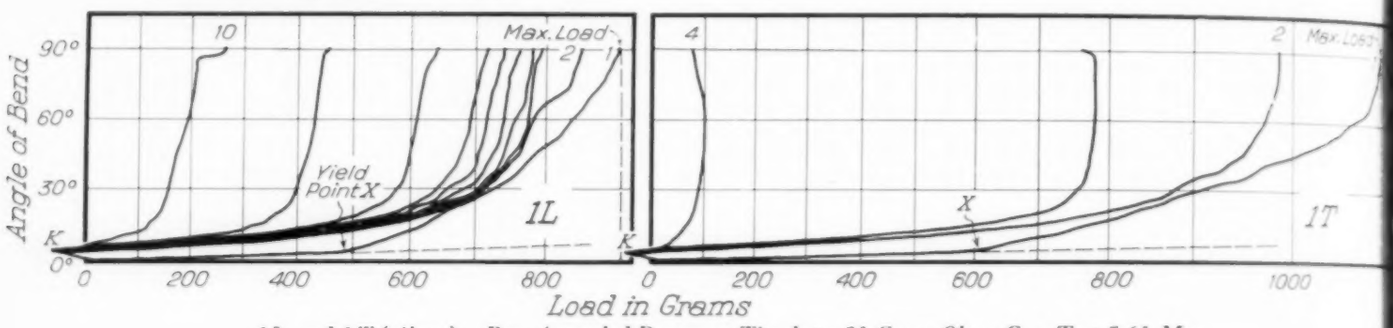
Some of the autographic curves for a few common varieties of tinplate will now be discussed, and will show that it is easy to distinguish them as to their reaction to repeated bending. Representative micros are also included, all cross-sections being cut longitudinally or parallel with the principal rolling direction, and magnified 100 diameters.

Autographs 1L and 1T (page 52) were made from two samples cut, respectively, longitudinally and transversely to rolling direction from a 31-gage (0.0109 in.) bessemer tinplate, hot pack rolled and box annealed. Curve 1, autograph 1L, is the initial bending curve for the longitudinal sample. Starting with clamps and pendulum in a vertical position, the pen records a straight line *O-X* at a small angle to the load ordinate. At *X* the ratio of angle to load changes and the curve makes a sweep upwards to the point of maximum load when the sample is bent 90° and motion at the hand wheel is stopped.

That there is a very marked change at some point *X* in the angularity of the curve must indicate that the specimen has been overstressed, either in part or all of its section. Microscopic study of bent sections of numerous samples representing a wide range in quality of commercial tinplate has shown that a very ductile sample will show much grain distortion and strain lines in its top surface layers, whereas the balance of

the section is apparently normal. On the other hand, a hard or brittle piece may show actual rupture of an outside section and the balance of the section badly overstrained. The autograph 1L is a fairly good example of the former type. Its failure was slowly progressive, requiring numerous repeat-bends.

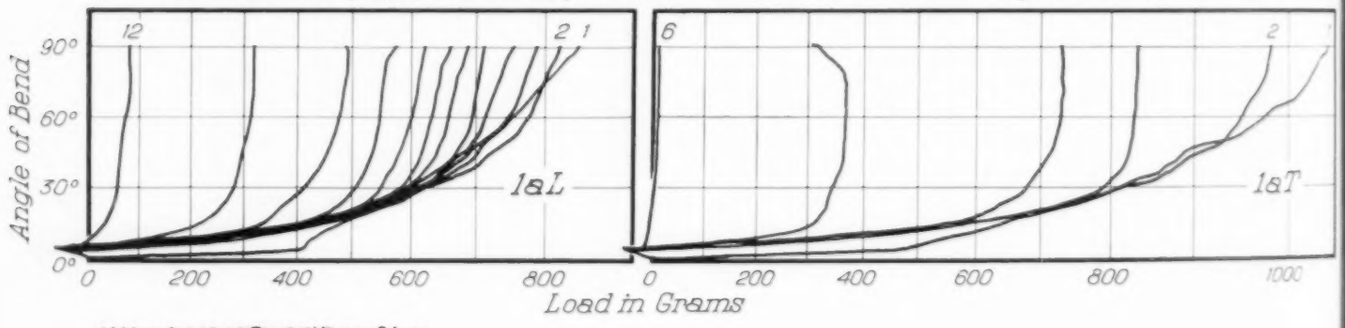
Continuing now with the description of the operation that produced autograph 1L: When the sample has been bent to 90° for the first time, the pen is removed from the drum and the operation of the hand wheel reversed. The pendulum moves back to the vertical position, or zero torque, is locked in that position, and the upper clamp thereby held vertical while the continual motion of the hand wheel forces the lower clamp to unbend the specimen and bring the lower clamp also to its original position. All moving members of the machine have now been brought back to starting position, the pen is again

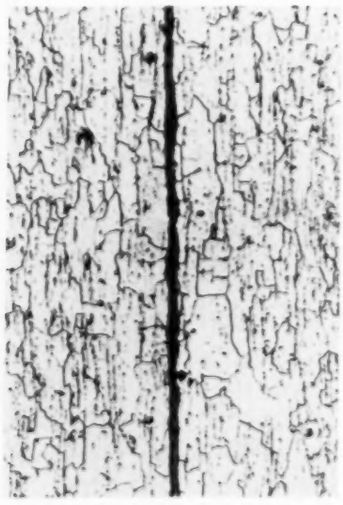


1L and 1T (Above): Box Annealed Bessemer Tinplate; 31-Gage; Olsen Cup Test 5.61 Mm.

Load-bend tests are taken on specimens cut longitudinally and transversely.

1aL and 1aT (Below): The Same After a Second Anneal at 1200° F.; Olsen Cup Test 6.42 Mm.





brought in contact with the drum and the operation for curve 1 repeated, thus producing curve No. 2. Repetition of the same operations produces the succeeding curves shown and, finally, complete rupture of the specimen.

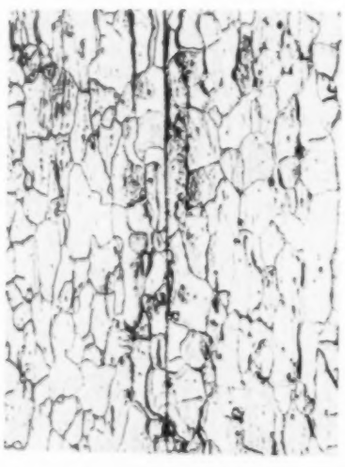
Autograph 1T was obtained in the same manner as was 1L. Compared with the latter, it shows a higher yield point, greater resistance to continued permanent deformation (that is, much greater load required to bend the specimen to 90° after the yield point has been passed, and therefore the piece is stiffer transversely than longitudinally), and is much lower in fatigue value — only four bends to complete fracture.

This comparison makes it quite obvious that the steel from which these specimens were taken has decided directional properties. Autograph 1L alone would indicate a medium soft tinplate

having good physical properties, but when autograph 1T is superimposed, the resulting composite presents quite a different picture. Autographs 1aL and 1aT are of the same shipment after the tinplate had received an additional anneal at 1200° F. The Olsen cup test has been improved (now 6.42 mm. against 5.61 mm. originally), the grain size enlarged, and the transverse weakness mitigated to a considerable degree. Material of this character is quite typical of box annealed bessemer tinplate, and is very suitable for flat work, where rigidity is a first consideration.

Three other sets of repeated bending curves, longitudinal and transverse, are shown on pages 53, 54 and 55, together with micros and results of Olsen cupping test, to indicate how the appearance of the autographs changes with method of manufacture. Some of them have practically no difference in directional properties.

Regardless of whether this method of testing light gage metals represents a fundamental study of the mechanical behavior of those materials, it has proved of definite usefulness by enabling us to judge, speedily and inexpensively, and within a reasonable degree of accuracy, the suitableness of tinplate for a specified purpose. By its indication of such properties as pliability, yield point, reaction to stress beyond the yield point, fatigue resistance, directional properties, measurement of work — all in a comparative way, autographically recorded — it accomplishes more and indicates more than any one testing machine with which the author is acquainted.



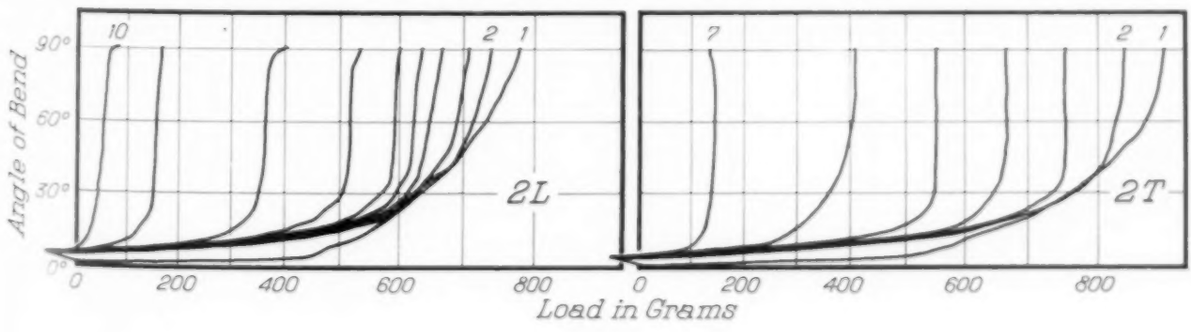
At this writing, four leading tinplate mills have equipped their laboratories with a bend tester of this type. This situation, of course, is very gratifying to us, for it indicates that these mills not only have put their stamp of approval on this method of determining the physical properties of light gage tinplate, but that by adopting a common method of interpreting these physical properties concerted action is finally under way to establish definite and acceptable means by which tinplate and other light gage sheet may be graded.

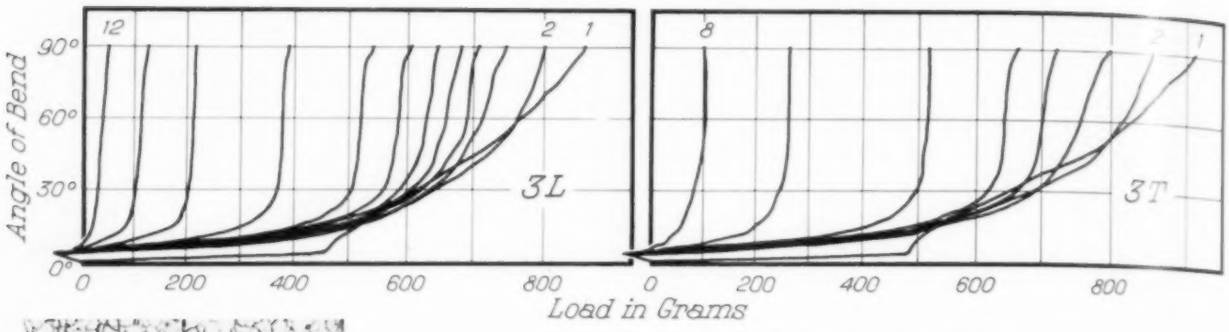
Bending and Unbending

The autograph at the foot of page 54 illustrates another type of curve that may be obtained by this apparatus. The material tested is the same as in 2L, namely 31-gage, box annealed, openhearth tinplate, tested longitudinally. In this procedure the pen is not removed from the paper when reaching the maximum load, but is left in contact during the reverse or clockwise operation of the machine. As the return movement of the lower sector gradually reduces the stress on the specimen, and the pendulum begins its backward balancing swing to the vertical, the pen will record a fairly flat line intersecting the vertical axis at some point *A* when the pendulum has reached the central position. At *A* the angle between clamps will be 90° plus a small angle created by the resiliency of the specimen — the bend has opened up a little.

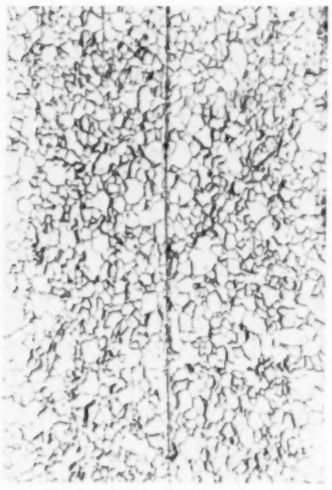
As the hand wheel operation continues in reverse, the specimen becomes stressed in the opposite direction. As this stress increases, always balanced by the pendulum (now also moving clockwise in an arc away from the vertical), the angle between the clamps increases until, as desired in this case, it is 0° and the specimen has consequently

Box Annealed Openhearth Tinplate; 31-Gage; Olsen Cup Test 7.13 Mm.





3L and 3T: Cold Reduced Strip; 31-Gage; 82% Reduction, Annealed; Then Given a Heavy Skin Pass

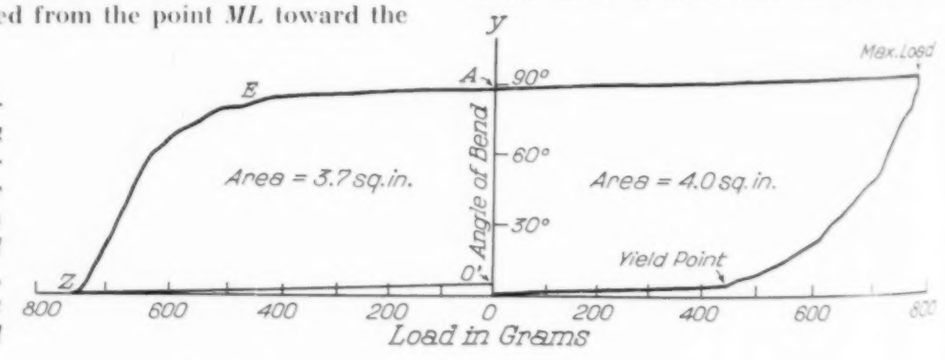


been fully unbent. During this time the curve *A-Z* was produced. Again reversing the operation, counterclockwise this time, the whole system is brought back to zero along the line *Z-O'*.

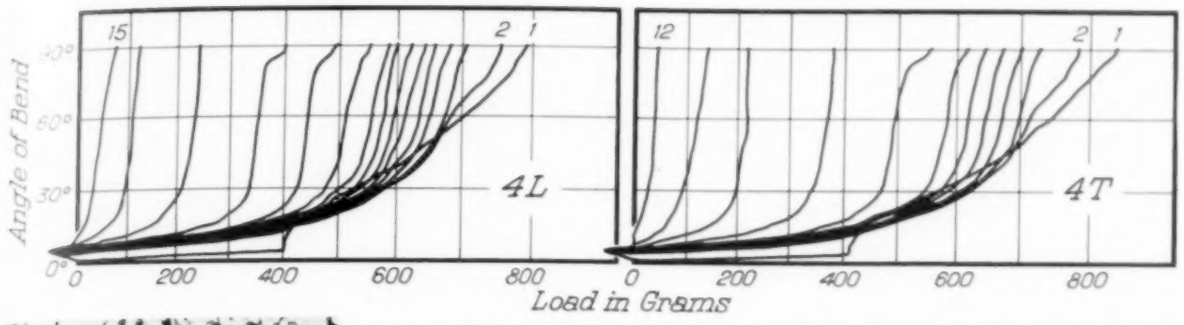
A graph of this character indicates not only what occurs during the initial bend of 90°, but what occurs when the specimen is unbent back to 0°. The work involved in both operations may be compared, not only by the shape of the curves themselves, but also by measuring the areas enclosed with a planimeter. The reverse curve and its area tells us that this plate will resist bending and unbending almost to the same extent (in terms of work expended). Such information is most useful in connection with certain highly developed container parts which are subject to considerable pressure. Being able to test the tinplate intended for these parts, not only for the amount of work required to deform it, but also for the amount of work required to undo that deformation, affords valuable advance information.

Still referring to the last autograph, it will be noted that for the unbending operation there is no straight line portion corresponding to the initial line between *O* and the yield point. This is as would be expected. As the bending load is reduced from the point *ML* toward the zero point *A*, those grains that were not stressed beyond their elastic limit are now causing a gradually increasing strain on those grains that are in the plastic state. The magnitude of the strain, compressive, in the plastic grains at zero pendulum is indicated at point *A;* in this case the net result has been to reduce the 90° bend to about 88°. By virtue of the mechanics of this testing machine, the plastic grains from this point on are subjected to further compressive stress with an increasing movement of hand wheel and pendulum. At point *E* the load rapidly exceeds the resistance of the plastic grains and the angle of bend is quickly reduced to zero. If this zero angle is not exceeded there remains, it seems, a degree of elasticity of compression which manifests itself as the pendulum load is again lowered to central position, and line *Z-O'* forming angle *O'-Z-O* with the load ordinate is the result.

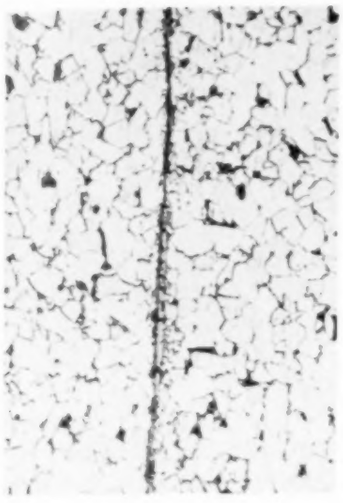
It will be noted that in the other autographs recording several 90° bends on the same sheet, there is a small part of each curve other than the first extending to the left of the angle ordinate *O-Y*. The reason is this: When the initial curve is made and the machine



Autograph Showing Load-Bend Relations During First Bending and Unbending of Sample 2L. Release of load from the maximum (point ML) causes gradual but small spring back, amounting to only about 2° in the material tested



4L and 4T: Sample of Tinplate, Normalized at 1700° F. in Pack of Eight



reversed preparatory to making the next curve, the pendulum, upon returning to the vertical position, is locked there until the clamps have also returned to the vertical, 180° apart, thus unbending the specimen to its original shape. To start operations for the second curve, the pendulum is first released; it is free to swing in either direction and immediately there is a kick to the left as is recorded at *K*, autograph 1L. This part of the curve is repeated for each succeeding curve, but grows weaker each time as the disruption of the structure increases due to fatigue. When the specimen has been straightened out, those grains whose elastic limit of compression was not exceeded exert a counter stress of a magnitude indicated by the kick-back. Of just how much value this part of the curve may be remains yet to be developed.

Origin of Porosity in Tin Coatings

By A. W. Hothersall and J. C. Prytherch

Condensed from Journal, British Iron & Steel Institute

ONE OF THE CHIEF DEFECTS in hot-dipped tin coatings on steel (tinplate) is the presence of pores or discontinuities in the coating, at which the underlying steel is exposed. An examination has been made of tinplate of various grades, with the object of determining the location of pores in relation to surface peculiarities or imperfections. The results of this examination have enabled the authors to assess the importance of certain types of imperfection in the tinplate as a source of pores in the coating, and indicate lines of future study.

Preliminary examination showed that a large proportion of the pores were associated with scratches in the coating, made subsequent to tinning. A number of sheets of tinplate were withdrawn at two stages in the process — on emerging from the grease-pot rolls and on emerging from the cleaning machine. Examination of these samples enabled a distinction to be made between defects present on the sheet as it emerges from the tin-pot and those produced subsequently in cleaning and polishing. All the sheets examined were "primes."

The degreased specimens were immersed in hot distilled water long enough to develop rust spots in the pores, and a map made of the surface, which was later de-rusted electrolytically and ruled with coordinate lines to which all subsequent microscopic examinations could be referred.

Pores were found to be chiefly associated with the following peculiarities or imperfections in the coatings: Grease marks, "scruff bands" and transverse ripples.

Grease marks are saucer-shaped depressions in the tin coating, frequently joined by narrow channels running approximately in the direction of tinning. They vary in diameter from about 0.001 to 0.020 in., and appear to be associated with runnels or drops of molten grease carried up by the sheet as it emerges from the top pair of grease-pot rolls. Grease marks have been found on all the samples of tinplate so far examined.

In common with other imperfections described in this paper, grease marks are more clearly visible on sheets taken from the top of the grease-pot rolls without having been subjected to any polishing treatment. Grease marks are more apparent in heavy than in light coatings. The depth of the grease marks, measured *(Continued on page 96)*

Typical Microstructures

of some

Alloy Cast Irons

By M. F. Surls and F. G. Sefing

Michigan State College, Lansing, Mich.

Micro by J. A. Comstock

LITERATURE concerning gray iron has given much information on the effects of various alloys on the structure and physical properties of base irons of this or that nature and analysis. The combinations that have been reported show results of considerable value to the gray iron producer who desires to meet specific requirements in microstructure, hardness, tensile strength and stiffness.

It is now our aim to show the characteristic effects which the common alloying elements have on the microstructure of a specific gray iron. It will also be evident that these effects are similar in many respects to those produced by these same elements when added to steel.

The gray iron selected for this purpose had about 3.20% carbon and 2.20% silicon. Its structure, as shown on the data sheet in METAL PROGRESS last month (page 57), was made up of characteristic dendrites consisting of pearlitic areas surrounded by fine, lacy graphite associated with ferrite. A series of photomicrographs (the data sheet last month, the one opposite, and the last to appear next month) shows the result both of adding the various common alloying elements separately and in logical combination. Some of the physical properties of the resulting alloy are also presented in a row of figures underneath each micro.

All the alloy cast irons were made from the same base iron which was melted in an indirect arc, rocking type, electric furnace. Charges were 300 lb. each, 80% pig iron and 20% steel. The metal was melted and the bath brought up to 2900° F., and about 60 lb. was tapped without delay into a preheated ladle. Measured amounts of ferro-alloys were added to the ladle as the metal flowed in. The iron was allowed to cool in the ladle to 2600 to 2650° F. and then poured immediately into dry sand molds for the standard arbitration test bar.

The following ferro-alloys were used: 92% "F" nickel shot, 68% ferrochromium, 80% ferromanganese, 61% ferromolybdenum, 41% ferrovanadium, and 18% ferrotitanium. No ferrosilicon was used in these heats. No attempt was made to adjust the chemical analysis to obtain the ideal conditions for each alloy; rather, the alloying elements were added to the same base metal in order to study the effect of each one under uniform conditions.

Four heats were necessary in order to obtain all of the alloys we desired to study. The base metals from the several heats were inspected and all were found to have the same type microstructure and similar physical properties. Variations in the analyses of each heat were well within the practical limits of the type of iron desired.

Inspection of the results makes it evident that the addition of an alloying element to cast iron may have two principal effec's on the microstructure: First is its effect on the amount, size and shape of the graphite flakes. Second is its effect on the amount of cementite, ferrite and pearlite in the iron. It also influences the fineness of the pearlitic structure. The total effect is obviously to change the physical properties as well.

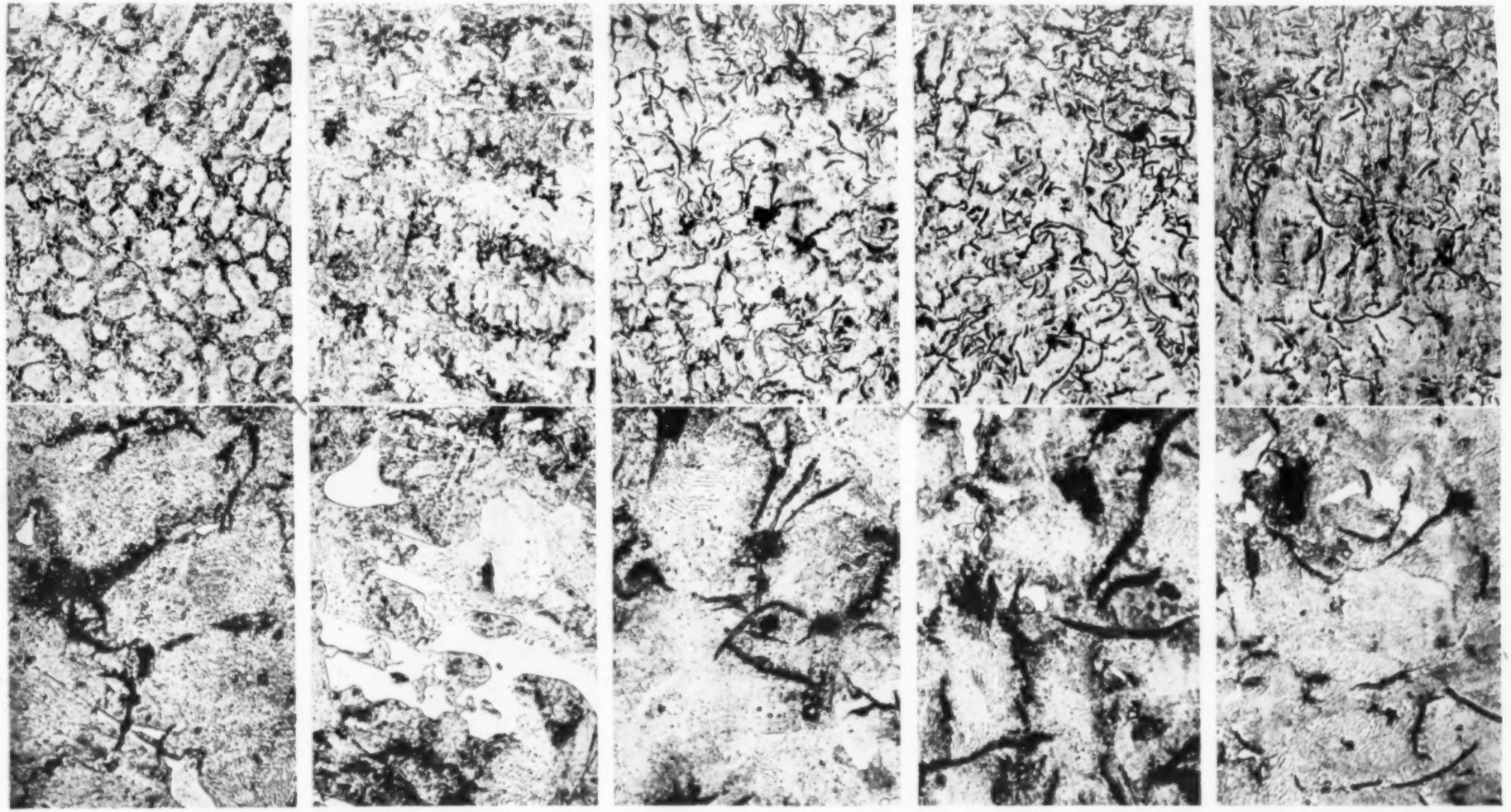
Alloying elements modify the *matrix* of the cast iron in essentially the same way as these same elements modify the structure of steel. Therefore, they should tend to produce changes in cast iron similar to those in steel.

METAL PROGRESS SEPTEMBER, 1936; PAGE 57

Typical Structures of Alloy Cast Irons; 2nd Sheet of 3

By M. F. Surls and F. G. Sefing, Michigan State College

Magnified 100 and 500 ×; Etched in 2% Nital



0.6% Chromium

Chromium, a strong carbide forming element, suppresses ferrite and lacy graphite, increases amount of clear cementite and makes pearlite laminations finer though less uniform

Combined carbon 0.82%
45,180; 243; 2610; 0.187

1.2% Chromium

Combined carbon 1.68%
41,860; 345; 2320; 0.144

1.7% Ni; 0.6% Cr

Contains virtues of both alloys and none of their faults; fine pearlite and no excess ferrite

Combined carbon 0.86%
44,240; 264; 2525; 0.200

3.45% Ni; 1.2% Cr

Dendritic with graphite plates; cementite is evidence of unbalanced analysis (too much Cr)

Combined carbon 0.81%
46,820; 296; 2450; 0.179

0.9% Ni; 0.25% Cr; 0.9% Mo

Excellent structure — dendrites eliminated, fine graphite flakes and exceedingly fine pearlite

Combined carbon 0.84%
50,080; 260; 2870; 0.228

The figures in the last line refer, respectively, to the ultimate tensile strength in psi., Brinell hardness, transverse strength in lb., and deflection in in. of the alloy iron above

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Spectrograph

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By M. F. Hasler and R. W. Lindhurst

Applied Research Laboratories

Los Angeles, Calif.

For Quantitative Work Two Exposures of the Unknown's Spectrum Are Made With Rotating Sector in Front of Camera Opening; Length Between Adjacent Line-Endings Is an Inverse Measure of Amount of the Element Responsible. The iron spectrum at the left is for registry and calibration

SINCE the first analytical application of the spectrum was made over 75 years ago the question is often raised as to why its use has been so limited in the intervening years in comparison with chemical methods. The reasons are apparently many, one among them being that the interested physicists were too absorbed in studies of atomic structure and in astronomical applications to lay a firm basis of analytical practice and instrumentalism. A man like Rowland for instance was more interested in producing gratings with which he could accurately plot the solar spectrum than in developing analytical technique applicable to terrestrial problems.

Of late years, however, we are witnessing a renaissance which bids fair to bring spectrography into every analytical laboratory where, because of its fundamental character, it rightly belongs. One of the chief reasons for this movement has been the perfection of instruments having adequate dispersion and resolution. With these instruments a limited group of problems demanding apparatus of high sensitivity and certainty have been solved in a manner that illustrates some of the possibilities of the spectrographic method. Even yet this includes but a very small region of the total analytical field in which the spectrograph is sure to make itself indispensable.

The first goal of all analytical work, of course, is to present a complete elemental qualitative and quantitative analysis. Further goals are to show molecular and solid linkages in material so that physical properties beyond the purely empirical may be studied. Here molec-

ular spectra and absorption spectra are destined to play an important part.

With the exception of work on absorption spectra, commercial spectrography is now principally limited to the elemental analysis of a substance by means of bright line atomic spectra. Since most of the known elements have their spectra measured with a high precision, the detection of all elements is feasible. The whole practical problem is to excite sensitive lines of *all* of the elements in a region of wave-lengths within the scope of present day instruments and photography. Of the various methods for producing spectra — arc, spark, discharge tube and high frequency oscillations — the first is the most adaptable to metallurgical problems, because it discloses all of the metals and quite a few non-metals with great certainty even if present in very low concentrations in the sample. This wide range of identifiable elements permits qualitative analyses, complete with the exception of sulphur and selenium, low quantities of phosphorus and carbon, and occluded or combined gases. This includes the detection of metallic constituents down to the order of 0.001%. Realizing the effects of small impurities, such an analysis becomes a positive necessity; all metallurgical advances are bound to emphasize this fact.

Progress is being made at a rapid rate in the field of quantitative spectrographic analysis. Much work is now being done to allow the measurement of minor constituents where an accuracy of about 90% is allowable. As research is furthered in this field, general methods will undoubtedly be worked out which will allow complete analyses with about this accuracy on any type of metal. At present, known comparison standards must always be utilized to produce curves correlating an element's concentration to the intensity of its spectral lines. As methods and equipment become more systematized, reliance on such standards will become less necessary, and high speed will be obtained on the occasional analysis — as it is now in routine work.

Spectrographic equipment suitable for general metallurgical analysis must fulfill certain rather rigid specifications; unfortunately, many commercial instruments fail to do so, and this has caused much misunderstanding and consequent disapproval of the method for reasons that are not often justifiable. Most important of these specifications is resolution, or the ability of the spectrograph to separate spectral lines a few tenths of an Ångstrom unit apart in all regions of the useful spectrum. This quality is absolutely essential in analyzing alloys high in tungsten, iron, chromium, nickel, cobalt, and vanadium with abundant spectral lines.

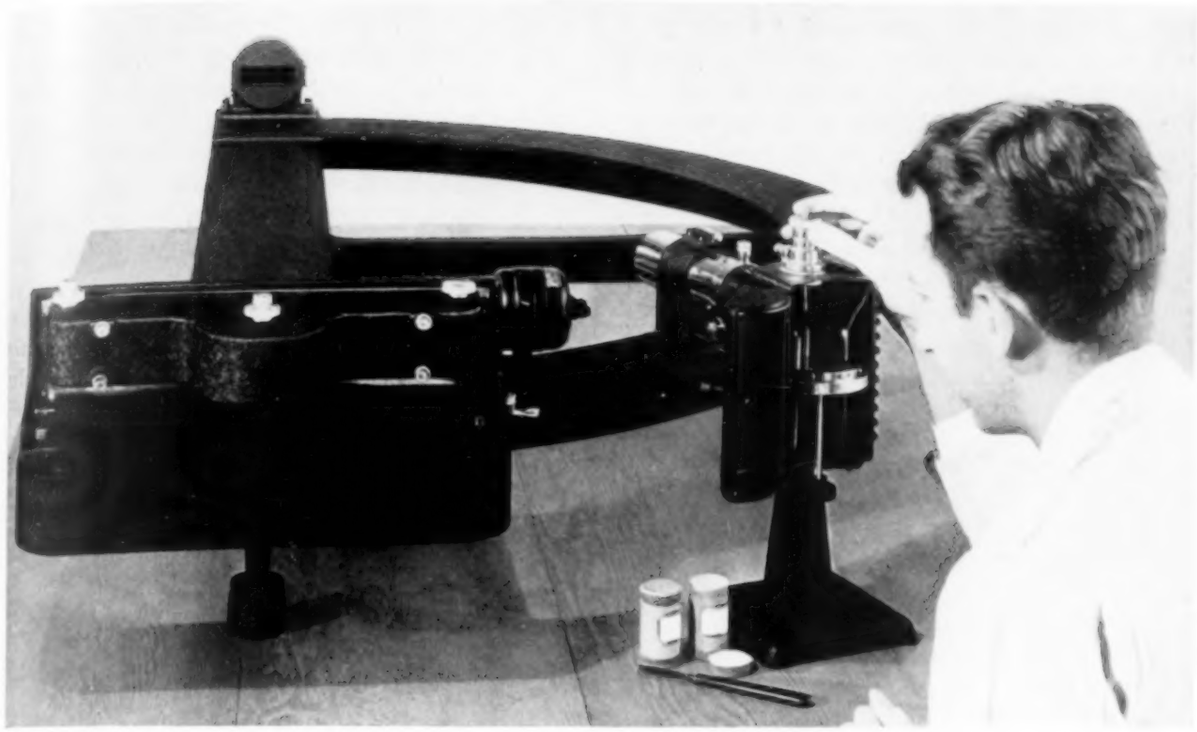
A factor contributing to practical resolution is "dispersion," which is the term for the spread of the spectrum. The spectrum must be sufficiently spread out on the photographic record, so that the grains in the emulsion and halation in the film, caused by intense lines, do not limit the resolution. On the other hand, as much of the spectrum as possible should be photographed on a single film, so that a complete analysis may be made with one exposure.

Grating Has 48,000 Lines

It was with these essential requirements clearly in mind that the spectrographic equipment about to be described was developed. To attain higher resolution than commercial prism instruments allow, a grating of 48,000 lines was selected as a diffracting medium. Adequate dispersion or spread of the spectrum was achieved by ruling these 48,000 lines over a two-inch length of concave optical surface having a 150-cm. radius of curvature. In favorable contrast with prism types (which inherently crowd the scale toward the red end of the spectrum) this model of grating instrument has a dispersion of 7 Å. per mm. of film, and this is uniform in all the spectral regions. Such characteristics obviously allow adequate dispersion at all wave-lengths without using films unduly long. The result is that 2200 Å. may be photographed on a 12½-in. length of film, and, for example, two exposures can include the region from 2400 to 6800 Å.

Another feature of interest is the surface of the grating. A coating of high reflectivity is evaporated upon the base metal, which provides the instrument with unusually high photographic speed both in the visible and ultraviolet. It is comparable in this respect with any instrument of similar dispersion. (While on the subject, it is well to mention that earlier experience employing gratings in analytical work has often led to poor results because of the presence of spurious "ghost" lines, due to errors in ruling. The gratings used in this instrument are of such precision, however, that for all practical purposes this objection is eliminated.)

Realizing that besides high excellence of spectrum photography many other details con-



Features Contributing to Rapid Work Are "Rowland Circle" for Mounting Arc-House, Arc-House With Rotary Table Containing Eight Electrodes, and Adjustable Camera for Six Exposures on 35-Mm. Motion Picture Film

tributing to analytical speed and accuracy are required, the grating spectrograph is supplied with a number of unique innovations. The half-tone above shows that the spectrograph is quite a departure from the conventional instrument using a prism. The semi-circular frame allows the analyst to photograph different regions of the spectrum by mounting the slit and the arc-house at various positions on the so-called Rowland circle. Since a change requires only the loosening of two thumb screws, it may be done in a few minutes without any readjustment of the rest of the instrument. The arc-house seen directly before the operator is of novel design, and encloses a rotary table holding eight electrodes. In one loading a number of portions of one or several samples may be arced. The self-spacing upper electrode is a convenient means for striking the arc, while a quartz condensing lens focuses the light given off by the material onto the slit assembly. The latter defines the light falling on the grating, mounted in a housing provided with lateral doors so that various areas of the grating may be exposed, thus offering a convenient means for changing the speed of the instrument.

The camera in the foreground is designed to accommodate 35-mm. motion picture film. It is loaded with a 100-ft. spool and has provisions for removing single 12½-in. exposures. By means of a masking arrangement at the front of the camera and vertical adjustment of the camera proper, four spectrograms of samples for qualitative work and two iron comparison spectrograms may be photographed on a single film. These iron spectra are used for alignment and calibration.

In using an instrument of this type for general analytical work, it is desirable to photograph a single spectral range which will include very sensitive lines of all 70 detectable elements. This is very important in custom analyses were complete results must be made in a minimum of time. Careful study has shown that the region from 2380 to 4600 Å. fulfills these requirements. The only exceptions are the alkali metals such as lithium, sodium and potassium, which do not have residual lines in this region though they do have others quite sensitive and adequate.

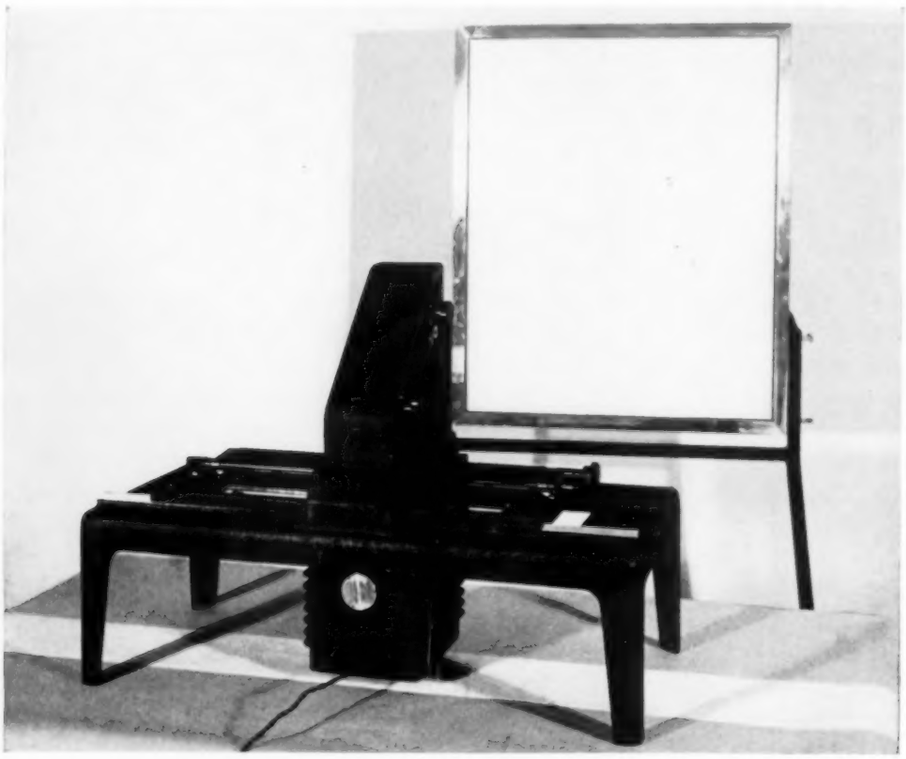
It may be of interest to describe briefly just how a metal alloy would be arced and its spectrum photographed. If ¼-in. rods of the metal are available they are used directly as electrodes. Otherwise drillings of the metal are placed in a cavity in two to four lower graphite electrodes, a multiple procedure which

minimizes sampling errors. Other variations due to arc fluctuations are averaged out by successively arcing each electrode for one minute, the opening on the grating being adjusted to give the correct exposure. Other exposures of the same material or of other materials may be made on the same film. After each pair of exposures of the unknown, the iron electrode is arced and an iron reference spectrum is photographed on the same film. It usually takes 5 to 10 min. to take several spectrograms of a sample and the calibration iron. Fast developers and fixers allow the film to be treated in about 5 min., after which it is allowed to dry.

For quantitative analyses the photography is very similar, with the exception that the mask at the front of the camera is replaced by a rotating sector, motor-driven. It varies the lengths of the lines according to their intensities, as shown by a portion of a sample spectrogram at the head of this article. The length between these adjacent line-endings is inversely proportional to the line's intensity. (A description of this method of quantitative measurement appeared in *Review of Scientific Instruments*, V. 7, No. 3, 1936.) Two exposures can be made on a single film with attendant iron spectra.

After obtaining the spectrograms of the samples to be analyzed, that method of measurement and interpretation must be employed which will extract from the film the greatest amount of information in the least time. To facilitate this a new instrument termed the "dual projection comparator" shown in the halftone below has been developed. It employs the well-known fact that certain lines of an element's spectrum are the most sensitive and that the identification of a few of these lines is a certain method of detecting the presence of that element in the sample. This premise is used in the preparation of a master film consisting of an iron spectrum and three or four lines of each of the detectable elements marked thereon. Thus a total of some 200 designated lines appear on the master film. By dual projection a small portion of the film bearing the sample's spectrum is shown directly over a portion of the master on a 24x30-in. screen. After aligning these two films exactly by means of the iron spectrum on each, the operator, in making an analysis, merely notes coincidences between lines in the unknown and lines of the seventy elements appearing on the master film.

To observe and tabulate the elements found



Unique Projector Enables Operator to Superpose, Accurately Register and Enlarge a Portion of the Film Containing the Spectrum of an Unknown on a Master Film Having Three or Four Lines of Each Detectable Element Accurately Marked

in an ordinary metallic alloy requires from 15 to 20 min. Doubtful coincidences occur rarely with an instrument of such high resolution, and always may be checked at other lines. In general qualitative work the intensities of the various lines are weighted visually to furnish an approximate quantitative estimate of the amounts of the elements present. In more accurate quantitative work the rotating sector is used and the distance between line endings is read on a vertical scale at the same time the qualitative check is made. Thus with a single instrument all tedious measurements have been eliminated, reducing errors by personnel, and increasing analytical speed and accuracy.

Before considering the question of the multitudinous applications of a complete set of instruments of the above type a discussion of the sensitivity of the grating spectrograph would not be amiss. Since no quartz-air interfaces are used in the spectrograph proper, stray reflected light does not limit the sensitivity as is often the case in Littrow mountings. Also, the higher resolution and dispersion affords greater general operational sensitivity since interference by halation from other lines is minimized. Thus sensitivities ranging from a few parts per million to a few parts per hundred-thousand have been recorded for all the true metals in a wide range of substances such as alloys, minerals, paints and pigments, glasses, food ashes, chemicals and ceramics.

To adequately survey the field of application of the spectrograph would be impossible, and since an excellent resume of the subject by Thomas A. Wright has already appeared in METAL PROGRESS in January, no such attempt will be made. Some pertinent specific examples, however, may be of interest.

In custom assay work, many metallic alloys are presented with the request for a "complete analysis." Often no indication is given as to the alloy type, and the chemist must start at the beginning and make a tedious and accurate qualitative analysis before attempting quantitative separations. In making these separations interference often occurs between various elements present, especially in complex alloys, and unless extreme care is exercised, minor constituents may be easily overlooked. With spectrographic equipment of the above type available, the first step is to arc the material; in examining the spectrogram with the projection comparator the operator prepares a list of all the elements detectable, usually 10 to 20 in number. At the same time he notes the intensities of the various lines used for identification, and from a table of factors calculates the approximate quantity of each element.

It has been found that estimates given to the nearest power of ten can be made quite accurately without consideration of the particular type of alloy, providing certain spectral lines are employed in estimating. These data will be available shortly.

A typical analysis would be the following:

Elements Present	*Approximate Quantity*	*Chemical Analysis*
Chromium	Principal Constituents	27.57
Cobalt		15.34
Iron		41.24
Silicon	1 to 10%	2.71
Tungsten	1 to 10%	9.26
Manganese	0.1 to 1%	0.18
Nickel	0.1 to 1%	....
Vanadium	0.1 to 1%	0.48
Boron	0.1%	....
Copper	0.1%	0.21
Calcium	0.01 to 0.1%	....
Magnesium	0.01 to 0.1%	....
Tin	0.01 to 0.1%	....
Molybdenum	0.01%	....
Silver	0.001 to 0.01%	....

That such a preliminary analysis is of tremendous assistance to the chemist is at once obvious, especially as it would only take approximately 30 min. A point of interest in the above analysis was that, in the chemical determinations, chromium and other elements tended to interfere with the vanadium so that it was entirely overlooked in the preliminary separations. Without the spectrograph as a watchdog, means for separating the vanadium would not have been realized and thus an error of importance could have resulted.

An example of a quantitative spectrographic technique applicable to routine analysis is the following problem: Determine alumina in iron ore in the concentration range from 0.5 to 5.0%; an accuracy of better than 90% is necessary and the average time allowable per analysis must be cut to a minimum.

In the solution of this problem a dry diluent was introduced to increase accuracy at high concentrations, and the iron content used as an internal standard since it was known from other analyses. A number of electrodes, rather than one, were filled with each sample of the diluted ore and arced for one minute each. (This procedure gives more uniform results than arcing a single electrode; correct *(Continued on p. 90)*

Steels & Alloys

for

Permanent

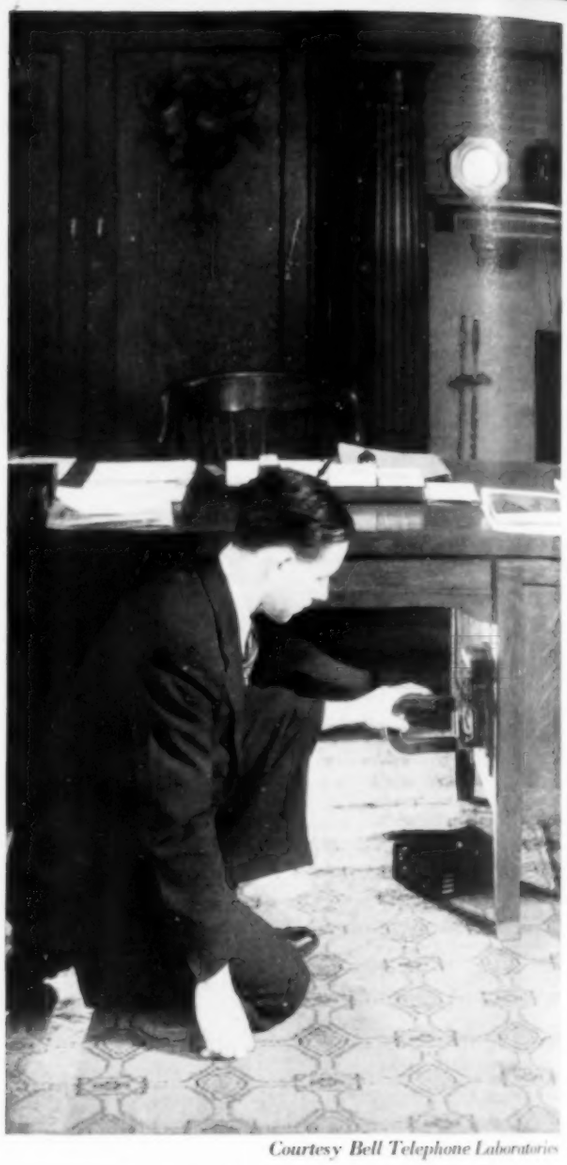
Magnets

By K. L. Scott

Engineer

Western Electric Co.

Chicago



Courtesy Bell Telephone Laboratories

Remagnetizing a Ringer Magnet

THIS ARTICLE, for the new 1936 edition of METALS HANDBOOK, is written during a period of great activity in the development of permanent magnet alloys. As a result there are commercially available two distinct types, namely, the older magnet steels, and the new, precipitation hardening alloys. There is a possibility that magnets made of compressed metallic oxide may be added as a third type.

Theory of Permanent Magnets

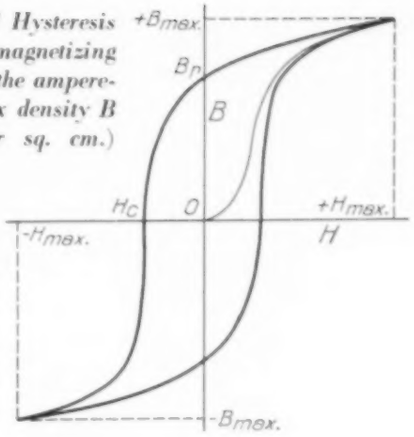
In order to understand the relative importance and usefulness of each type of material, a brief resumé of the methods of testing the permanent magnets will be given. In the top figure on the opposite page is shown a typical hysteresis loop and magnetization curve for a permanent magnet alloy. The variables are magnetizing force H and magnetic flux density B. If increasing values of H are applied to an unmagnetized specimen at O (as by gradually increasing the electric current in a coil of wire wound on the specimen) the corresponding values of magnetic flux produced in the specimen will be as shown by the normal induction curve, the light line. If now the values of H be gradually reduced from the highest applied value, $+H_{max}$, to zero and then increased in the negative direction to $-H_{max}$ (by reversing the current in the magnetizing winding) the value of B will change from a $+B_{max}$ to $-B_{max}$ along the left-hand heavy curve of the hysteresis loop. If this process be reversed, starting with $-H_{max}$ the right-hand side of the hysteresis loop will be traced.

If the value of magnetizing force be reduced from $+H_{max}$ to zero (as by opening the circuit of the magnetizing winding) the value of B will drop from $+B_{max}$ to the intersection of the hysteresis loop with the vertical axis and the value is called the residual induction, desig-

nated B_r. If there is now applied sufficient negative magnetizing force to reduce the value of B from B_r exactly to zero, the value of $-H$ required will be as shown by the intersection of the hysteresis loop with the horizontal axis. This particular value of H is called the coercive force, designated H_c.

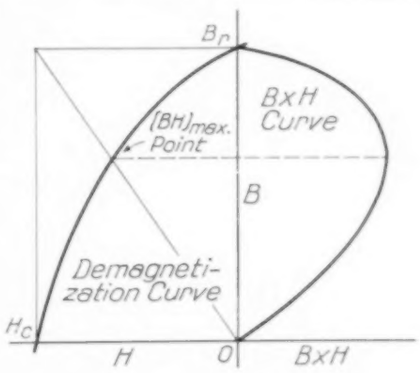
The descending branch of the hysteresis loop between the points B_r and H_c is most important in permanent magnet theory. It is known as the demagnetization curve. If the product of the coordinates, B and H, of this curve is plotted against corresponding value of B, a new curve is obtained, as shown in the middle figure. The maximum value of the product $B \times H$, designated $(BH)_{max}$ as obtained from this curve, is proportional to the maximum amount of magnetic energy which a magnet of the given material can support in an air gap, per unit volume of material in the magnet. Hence, the most efficient magnet design will be one which works the magnet at the flux density corresponding to the $(BH)_{max}$ point of the material.

It is not necessary to plot the curve $B \times H$ vs. B to determine the value of $(BH)_{max}$ or the corresponding value of B. The coordinates of the $(BH)_{max}$ point are determined to a close approximation by the intersection of the diagonal of the rectangle having sides $(O - B_r)$ and $(O - H_c)$ with the demagnetization curve.



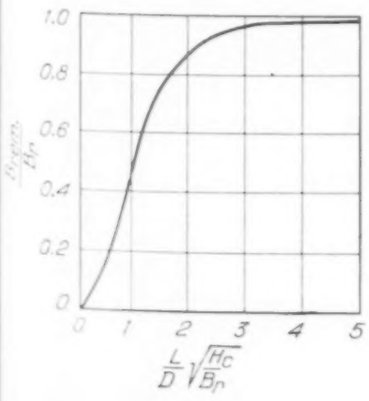
Typical Magnetization Curve and Hysteresis Loop. Coordinates represent magnetizing force H in oersteds (0.4 π times the ampere-turns per cm.) and magnetic flux density B in gauss ("lines of force" per sq. cm.)

Since the value of $(BH)_{max}$ is proportional to the maximum maintainable air gap energy per unit volume of a magnet, it constitutes a criterion of the magnetic quality of a permanent magnet material. It has been shown empirically that the quantity $(BH)_{max}$ is proportional to the product $B_r \times H_c$. Hence this product can also be used as a criterion of magnetic quality. It has also been shown that the coordinates B and H of the $(BH)_{max}$ point are equal respectively to approximately $0.65B_r$ and $0.65H_c$. Hence the determination of B_r (residual induction) and H_c (coercive force) for a material serves to determine its magnetic quality as a permanent magnet material, and also to determine the flux density at which magnets of the given material should be designed to work.



One Criterion of Quality of Magnet Material Is the Maximum Value of the Product B × H, Conveniently Determined From Demagnitization Curve (B_r to H_c in the First Curve) by the Geometric Construction Shown at the Left of the B Axis

It has been shown also that the flux density of a fully magnetized bar magnet, designated B_{rem} depends upon the length L and equivalent diameter D, in the manner shown in the lowest figure. This curve holds for all permanent magnet materials, and applies strictly only to straight bars, but suits magnets of other shapes quite well (unless the ends of the magnets are close together, or are brought effectively close together by iron pole pieces). In most cases the curve can be used as a check on the measured flux values of formed or cast magnets of various shapes when magnetized and tested as bar magnets. In these cases the actual flux values obtained should never be lower than predicted by the curve.



Flux Density of Bar Magnets (Vertical Ordinate) Depends Upon a Function of the Size (Length L and Diameter D)

Most manufacturers and large users of permanent magnet steels or alloys test the materials for magnetic quality by measuring B_r and H_c. The tests are made in some form of permeameter on straight bars of cast or rolled

material, after proper heat treatment. Methods and equipment for making these tests are described in A.S.T.M. Standard Method of Testing A34—33.

Most magnet users also make a flux test on the finished magnets. This test can be made most accurately with a search coil and a flux meter of the galvanometer type. Sufficient accuracy for commercial purposes and greater speed are obtained with flux meters of the direct current meter type in which the test magnet furnishes the field to deflect the moving coil of the meter.

Aging of Magnet Materials and Magnets

The magnetic properties of the permanent magnet steels are not stable with time. The residual induction and coercive force of most magnet steels begin to change spontaneously as soon as the steels are hardened and continue to change for an indefinite time. The rate of change is greatest immediately after hardening, and decreases rapidly so that in a few days the rate is slow. The rate and amount of change differ for different kinds of steel and are not uniform for any given kind of steel, but the *direction* of the change is always for the residual induction to increase and the coercive force to decrease. It is good practice to allow a specified aging period to elapse between the hardening and testing of test bars.

Because of the nature of the precipitation hardened alloys, and the kind of heat treatment employed, such aging phenomena are much less pronounced and may be absent in some of them. Even an *increase* of coercive force with time has been observed in test bars of iron-nickel-cobalt-aluminum with no change in residual induction.

The state of magnetization of magnetized steel magnets is also subject to a peculiar instability. It is observed that if magnetized immediately or soon after hardening they will spontaneously suffer a decrease in flux beginning immediately after magnetizing. The rate of loss decreases rapidly with time, so that after several days the flux has reached an approximately stable value. If the magnet is remagnetized, the same phenomenon is repeated on a smaller scale.

The phenomenon, however, is only temporary and disappears with a sufficient lapse of time after hardening; it is probably not present to any great extent in the precipitation hardened alloys. Data on this point are not available.

The loss of flux that occurs in magnets due to external demagnetizing influences is also commonly but improperly referred to as "aging." External demagnetizing influences include mechanical shock, adverse magnetic fields (this includes alternating current fields and the fields of other magnets) and heat. In general, if a magnet is weakened by any one of the above means, it will not be further weakened by a repetition of the same treatment and will suffer only a slight loss in flux from the application of any other treatment that would have weakened it originally by about the same amount.

In the process inspection of magnets after hardening, some users follow the magnetizing operation by a partial demagnetization or "aging," before testing. This partial demagnetization is for the purpose of eliminating magnets that are improperly hardened or made of defective material and is not intended as a stabilizing treatment. If a true stabilizing treatment is required, as for magnets to be used in measuring instruments, they may be stored for a long period of time, subjected to heat as by immersion in boiling water, or merely be partially demagnetized by an a.c. or d.c. field after final magnetization.

Methods of Magnetizing

The problem of magnetizing permanent magnets is becoming increasingly difficult with the advent of materials with coercive forces above 200 oersteds, since the magnetizing field required fully to magnetize a magnet is several times the coercive force of the material, amounting in some cases to as much as 1500 ampere turns per centimeter. The magnets made of low coercive force steels and most magnets made of cobalt steel can be fully magnetized by means of large electromagnets. Precipitation hardened magnets of favorable shapes can also be magnetized by the same means, but magnets of intricate shapes made of cobalt steel or the precipitation hardening alloys can only be fully magnetized by winding heavy wire on each magnet and sending a heavy current through the wire by shorting the winding across a suitable source of heavy current. In this case, it is advisable to protect the current source and the winding by using a fuse in series. The fuse wire will melt and open the circuit before damage occurs to the current source or the magnet winding.

The types of magnet steel produced com-

mercially in the United States are classified by their manufacturers as follows: Carbon-manganese, chromium, chromium-molybdenum, tungsten, and various grades of cobalt steel including cobalt-chromium and cobalt-tungsten. The chromium steels are made in grades ranging from nominal 1% chromium to 6% chromium, the tungsten steel ranges from 5 to 6% tungsten, and the cobalt steels contain from 3 to 36% cobalt with chromium from 2 to 10% and tungsten from 1 to 10%, and a fraction of 1% molybdenum in some cases. Sometimes the tungsten steels contain sufficient chromium to make them oil hardening. Otherwise, the tungsten steels, the 2% chromium steel, and the carbon-manganese steels are water hardening and all the rest are oil hardening. It is noteworthy that the 1% chromium steel has the best magnetic properties when quenched in oil, but that water, some water solution, or a light oil are universally recommended for the 2% chromium steel.

Commercial Types of Magnet Steels (American)

Type of Steel	Nominal Composition, %(a)						Magnetic Properties(c)		Hardening Temperature, °F.	Quenching Medium
	C	Mn	Cr	W	Co	Mo	B_r Gauss	H_c Oersteds		
C-Mn	0.60	0.80	—	—	—	—	10,000	43	1450	Water
Cr	0.60	0.40	0.90	—	—	—	10,000	50	1450	Oil
	0.90	0.35	2.25	—	—	—	9,000	58	1500	Water, Oil
	0.95	0.20 to 0.60	3 to 4	—	—	—	9,500	63	1525	Oil
	1.00	0.35	6	—	—	—	9,000	72	1550	Oil
Cr-Mo	1.00	0.35	4	—	—	0.35	9,000	65	1550	Oil
W	0.70	0.30	0.20	5.5	—	—	10,000	65	1550	Water
W-Cr	0.70	0.50	0.50	6	—	—	9,000	70	1525	Oil
Co	0.90	0.35	4.75	1.25	8.5	—	7,500	120	1650	Oil
	0.90	0.30 to 0.85	3.50 to 5.75	3.75 to 7.0	35 to 41	—	9,700	235	1700	Oil
Co-Cr	0.95	0.30	9	—	16	1.30	8,000	180	(b)	Air
Co-W	0.85	0.50	2 to 5	8.75	17	—	9,000	165	1750	Oil

(a) Silicon limit usually 0.30% max., phosphorus and sulphur 0.03% max., nickel 0.50% max.

(b) Triple heat treatment, 2100°F. cool in air, 1150°F. cool in air, 1850°F. cool in air.

(c) Nominal values after hardening. Values for previously annealed materials usually 5 to 10% lower in H_c

Manufacture of Magnets from Steel

Data concerning the various types of magnet steel are shown in the adjoining table. Only those types reported by various American manufacturers are included, and the data are summarized from information furnished by them.

In general, the methods of melting, rolling, and fabricating are similar to those used for tool steels of similar composition. Exceptions arise from the fact that mechanical properties are of secondary importance and practices which would be harmful to the magnetic properties must be avoided. In particular, this means that the thermal history of the steel should be brief; rolling or forging should be accomplished with a minimum amount of reheating. Annealing should not be resorted to unless necessary for machining operations and the anneal should be as light as is consistent with machinability. Forming temperatures should be just high enough for proper working of the steel. It is rarely feasible to restore the magnetic properties of magnet steel that has been damaged by too prolonged heating or overheating.

Magnet steels are melted in electric furnaces, either arc or induction. One exception lies in the use of openhearth furnaces for melting carbon-manganese steel and the chromium steels of lower chromium content where larger tonnages are involved. In some cases ingots are cooled in lime, dry sand, or other material before rolling, but where possible it is preferable to break them down without cooling. This is done either by forging or rolling. Surface defects are generally removed by grinding. Rolling temperatures at start range from 1800 to 2100° F. and the finishing temperatures from 1300 to 1700° F., depending upon the critical temperature of the steel.

In most cases, the shapes of permanent magnets are such as to require hot forming.

This may be done satisfactorily at temperatures between 1400 and 1800° F. A medium temperature is preferable and the heating and forming should be done as quickly as possible. Magnets are generally air cooled after forming. Some magnets are hardened by quenching immediately following the forming operation, thus eliminating one heating operation, but this practice requires better than ordinary control of the forming temperature.

Too much emphasis cannot be laid upon the desirability of designing magnets so that they do not require annealing for some machining operation. Where this is unavoidable, as light an anneal as possible should be used, for annealing always damages the magnetic properties. Air hardening grades of steel must be annealed by the fabricator after hot forming if machining is necessary; otherwise, annealing may be done at the mill if forming is not required or if the machining may be done before forming.

Magnet steel should be heated to the annealing temperature quickly, held at temperature only long enough to be heated through and cooled just slowly enough in the furnace to avoid air hardening. In all cases, cooling from 1000° F. to room temperature may be done in the open air, since no air hardening will take place below 1000° F.

The recommended hardening temperatures are specified in the table. The optimum hardening temperature is that which gives the highest value of the product $B_r \times H_c$, except that some magnets are not designed for maximum efficiency and require higher values of B_r or H_c than are associated with the maximum value of their product. High values of B_r (residual induction) are best for long or slender magnets and high values of H_c (coercive force) for short, thick magnets. Oil quenching results in higher values of H_c and lower values of B_r than water quenching. The latter results in a much greater amount of warping and cracking. For this reason oil quenching steels are gradually replacing water quenching steels for most applications. Magnets should not be held at the hardening temperature longer than is necessary to heat them through.

Great care must be exercised in grinding hardened magnets to avoid the production of grinding cracks, which sometimes develop hours after the grinding operation. Wet grinding and light cuts are the best safeguard.

Magnets of intricate shapes, chiefly made of cobalt steel, are frequently produced by casting. The properties of cast cobalt steel do not differ greatly from forged or rolled, although the coercive force is usually higher and the residual induction lower. The same annealing and hardening practices are recommended. Cast material is generally more brittle than forged.

Reliable correlation of microstructure with magnetic properties has not been accomplished, although advances in the theory have been particularly rapid in the last five or ten years. A very good statement of what is known and surmised about the relationships between atomic structure, space lattices and ferromagnetism is given in an article by R. M. Bozorth, "The Present Status of Ferromagnetic Theory" in Bell System *Technical Journal*, Jan., 1936.

As far as its grosser manifestations are concerned, a fine, silky fracture is generally associated with good material. Decarburization (non-uniformity) should, of course, be avoided. Heating above 212° F. after hardening is detrimental to the magnetic properties; actual damage begins to take place at from 300 to 400° F. Defective magnets may frequently be reclaimed by rehardening. There is, in general, no particular method of quenching in water which will minimize warpage or breakage. Tongs should be as light as possible to avoid cooling the magnets too much by contact with cold metal before the quench.

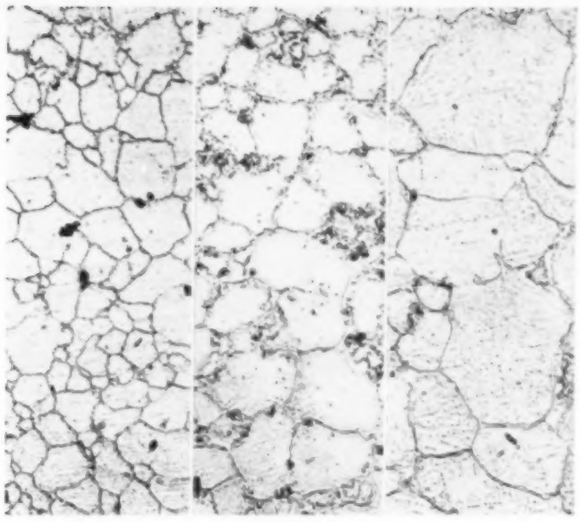
Precipitation Hardening Alloys

The range of possibilities for the design of permanent magnets has been greatly extended by the introduction of substantially carbon-free alloys of the precipitation hardening type. The magnetic properties of any of the permanent magnet steels can be substantially duplicated by some of the carbon-free alloys, possible to formulate. Other materials having coercive forces greatly in excess of any of the magnet steels are commercially available, with still others in process of development. The alloys appearing to have the greatest commercial possibilities at the present time are as follows: *(a)* an alloy of 72% iron, 12% cobalt, and 16% molybdenum (B_r=12,000 to 8500, H_c=50 to 300) *(b)* an alloy of iron with 10 to 25% nickel, 15 to 30% cobalt and 8 to 25% titanium (B_r=7600 to 6300, H_c=780 to 920) and *(c)* an alloy of iron with 24 to 30% nickel, 9 to 13% aluminum and 5 to 10% cobalt (B_r=10,500 to 7500, H_c=150 to 660). With possibly the excep- *(Continued on page 88)*

Correspondence

and

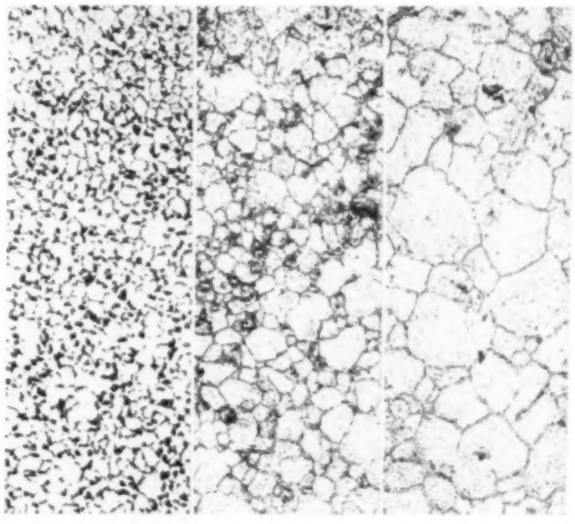
Foreign Letters



1550° F. 1750° F. 1835° F.

Austenitic Grain Boundaries Developed in Two Heats of S.A.E. 3135 by Preferential Oxidation at Heat Treating Temperatures. Smooth surface lightly ground, polished, and etched with 2% nital, and photographed at 100×

1550° F. 1650° F. 1835° F.



Austenitic Grain Size *marked by* Preferential Oxidation

PILZEN, CZECHOSLOVAKIA — The determination of austenitic grain size at various temperatures may be carried out by the methods described by Bain and Davenport in the ASM Grain Size Symposium, 1934 [and discussed in the article starting on page 39 of this issue]. The methods originally suggested seem to require an accurate knowledge of the critical cooling rate of the steel under investigation, and it is known that this may vary considerably with slight changes in the content of alloying elements. Owing to this circumstance the McQuaid-Ehn test is more widely employed in Europe, but its application is limited by the necessity of carburizing at temperatures which may exceed those attained in the normal heat treatment of the steel under study.

In the course of an investigation of austenitic grain size in alloy steels at the research laboratories of the Skoda works, the writer has found that preferential oxidation at grain boundaries may serve as a useful method for determining the grain size at all temperatures above the Ac_3 point. The test is carried out as follows:

A small sample of steel is finely ground (but not polished) on one side as for metallographic investigation. It is then inserted into an electric furnace heated to desired temperature with free access of air. The specimen is held for the desired time at temperature and then quenched in water or oil. The continuous layer of oxide on the surface is removed by grinding and polishing, and the polished surface is finally etched with 2% nitric acid in alcohol.

The grain boundaries are indicated either by accumulated oxides or by decarburized envelopes of ferrite. In some cases the ferrite layer at the boundaries is so thin as to appear as a single fine line at 100 diameters.

Care should be exercized not to grind the oxidized surface of the sample too deeply,

otherwise the microscope will show the martensitic structure of the core without any distinct grain boundaries. This would require a repetition of the experiment.

In order to prevent excessive scaling of specimens when they are held for a long time at high temperature the experiment may be modified as follows: The samples are heated in a good vacuum — pressure less than 0.1 mm. of mercury — and air is admitted at the end for at least 15 min. before quenching. If this time allowed for oxidation is too short (say less than 10 min.) the entire surface is uniformly decarburized, especially if the vacuum was poor — for instance — 10 mm. In such case misleading results can be arrived at.

The photomicrographs at the head of page 69 illustrate the grain growth of a chromium-nickel steel from two heats of approximately the same composition, corresponding to S.A.E. 3135. Each sample was held at indicated temperature for one hour. The differences in grain size between the two heats are due to different conditions of deoxidation during the final refining stages in the steel manufacture.

P. Herasymenko

Rapid Method of Developing Austenitic Grain Size

ROLLA, Missouri — Throughout the past two years three students at the Missouri School of Mines and Metallurgy (W. R. Gaddis, William Lenz, and Thomas R. Graham) have done some rather interesting work on the measurement of austenitic grain size. Their problem was to compare different schemes of developing and recording this structure in the various S.A.E. carbon and alloy steels.

A set of three views is shown at right, from many which exhibit the same fact, namely, that an interrupted quench from 1700° F. or a quench after developing the temperature gradient, will both give the same network size as the McQuaid-Ehn test (carburizing at 1700° F., in our experiments two hours in propane gas).

Our tests indicate that the shorter methods of developing grain size at 1700° F. can be depended upon to reproduce the same results in the ordinary run of plain and alloy steels as the much longer McQuaid-Ehn test at the same temperature.

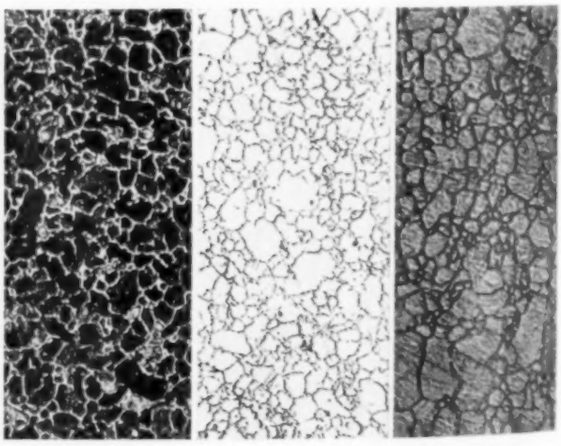
Charles Y. Clayton

Structural Hardening and Season Cracking of Solid Solutions

PARIS, France — There are few phenomena which have been more useful in the utilization of alloys than that of hardening by tempering, which produces a new phase in a supersaturated solid solution.

This phenomenon, first noted in the light aluminum alloys and for a long time unexplained, is produced in quenched metal during tempering, either spontaneously or by reheating, and is known as "age hardening," "precipitation hardening," or "structural hardening." The nomenclature was discussed by C. H. M. Jenkins in Metal Progress, June 1934. The present writer prefers the term "structural hardening" as being more general and precise, as we will see. Structural hardening influences mechanical strength, often considerably increasing it, and, inversely, decreases resistance to chemicals and corrosion by promoting intercrystalline corrosion. (Cracking corrosion or season cracking is nothing more than intercrystalline corrosion that is localized and spreads under the effect of latent or induced internal stresses.)

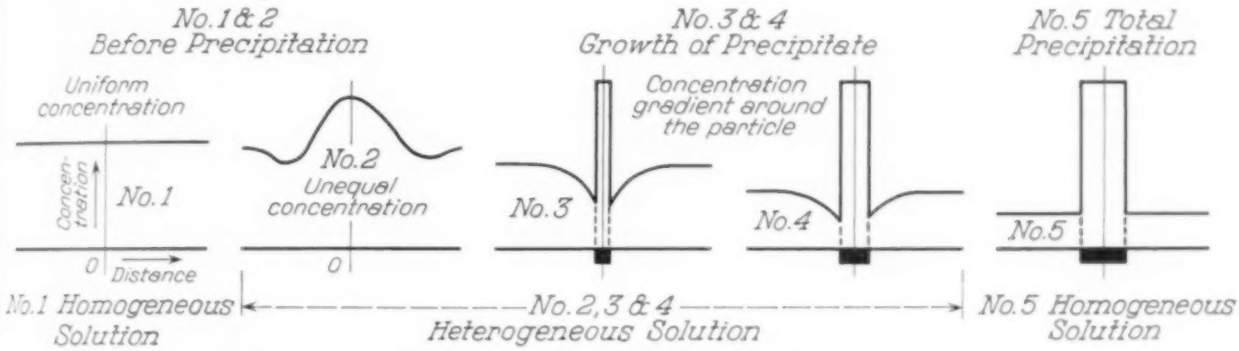
An ingenious explanation of this increase in mechanical strength or hardening has been given by Jeffries and Archer: Precipitation of fine particles within the crystalline grains of the solid solution prevents movement along slip



Grain Size of S.A.E. 2320 Hot Rolled Bar at 1700° F. Left, carburized at 1700° F. 2 hr. in propane gas, furnace cooled. Center, quenched from 1700° F. in iced brine after developing temperature gradient. Right, quenched from 1700° F. in fused salt bath at 1285° F. for 30 sec., then in water

planes under stress, thus increasing the resistance to plastic flow, particularly when the particles are of appropriate size and dispersion. As the particles continue to increase in size by coalescence, some of the slip planes become free and the resistance to deformation decreases; this explains the decreased hardness on prolonged tempering. Furthermore, corrosion is increased by the presence of these precipitated particles, which constitute a new phase and consequently give rise to electrolytic phenomena in conducting solutions.

Consequently, hardening (and corrosion) ought to be concomitant with precipitation. This is confirmed for some alloys, such as aluminum hardened by the compound Mg_2Si; however, in the aluminum-copper alloys hardening



Diagrammatic Representation of Five Stages Starting With Uniform Solid Solution and Ending With Total Precipitation (Both Ideal Conditions)

and a concentration-gradient around this particle, as shown by diagrams No. 3 and 4 on the attached figure. This gradient (and, consequently, the decrease in the average concentration) is more marked (*a*) as the rate of precipitation increases, since the precipitation rate depends on degree of supersaturation, and (*b*) as the rate of diffusion decreases, since the diffusion rate decreases rapidly as temperature falls. The phenomenon is thus accentuated in precipitation at low temperature and diminishes when the temperature rises — that is, after long stay at temperatures permitting diffusion to occur at a measurable rate.

An inequality and inhomogeneity in the concentration, however, not only accompanies but necessarily precedes precipitation (see diagram No. 2 in the attached figure). Evidently the precipitates can only form when there is a preliminary accumulation of molecules of precipitate resulting from diffusion within the liquid. This lack of homogeneity and prior and necessary disturbance of the ideal uniform concentration in the solid solution explains the phenomenon under consideration.

precedes precipitation (that is to say, precipitation as revealed by various physico-chemical methods). On the other hand, the presence of precipitated particles cannot alone explain some kinds of corrosion, such as the intercrystalline corrosion of 18-8 stainless steels after heating at a moderately elevated temperature, cooling, and subjecting it to solutions otherwise innocuous.

Various ingenious interpretations have been proposed of the processes of structural hardening; all have the drawback of being complicated, hypothetical and not accompanied by direct experimental proof. Nevertheless, it is only necessary to consider the elementary and self-evident precipitation process to find a satisfactory explanation.

When a particle of the precipitate forms and develops within the solution, the atoms necessarily migrate from the solution to the precipitated particle by diffusion. This naturally results in a zone of lower concentration

X-ray studies of a series of solid solutions with varying proportions of solvent and solute prove that the dimensions of the crystalline lattice depend on the amount of solute atoms dissolved in the solid solution (and, according to Végard's law, variations of the lattice and of the concentration are often proportional). Consequently, uneven concentration such as sketched in No. 2 causes deformations in the lattice and in the main crystallographic planes along which slip occurs — in other words, causes resistance to deformation in the crystalline grains, revealed by an increase in hardness of the alloy. Such an interpretation, added to that

of Jeffries and Archer, presents a complete and precise explanation of the whole hardening phenomenon.

Turning now to a specific case, the decreased concentration of chromium in the solid solution surrounding precipitates of chromium carbide when 18% chromium, 8% nickel stainless steel is heated at relatively low temperature (in the range 800 to 1500° F.) has already been indicated by Bain, Aborn, and Rutherford in Chapter 14-B of The Book of Stainless Steels as the explanation of intergranular corrosion accompanying this precipitation; the solid solution, deprived of chromium, is made susceptible to attack at these impoverished regions. The phenomenon becomes more complicated if the austenitic solution becomes so low in chromium that it transforms to the alpha state at room temperature — a condition that explains the chemical attack even better.

The lack of homogeneity in solid solutions of iron-nickel-chromium-carbon can be revealed and quantitatively studied by thermomagnetic analysis (see my letter in METAL PROGRESS, February 1935, p. 42), the maximum difference in chemical composition, point to point, depending upon the position and spread of the Curie magnetic point on a heating and cooling curve. It is thus possible, first, to prove directly the lack of homogeneity in the solid solution preceding the precipitation of discrete particles, and second, to show experimentally that this lack of homogeneity affects the mechanical and chemical resistance at least as much as the precipitation itself.

In non-magnetic alloys such as the light, hardenable aluminum alloys, this postulated lack of homogeneity in the solid solution can be confirmed by X-ray spectrographic study. The doublet $K\alpha_1$-α_2, which is sharply marked for uniform, unstrained alloys, becomes less and less distinct as the lattice planes are distorted due to unequal concentration. It is also possible in this way to verify the statement that this lack of homogeneity *precedes* actual precipitation.

Hence, precipitation within the solid solution is preceded and accompanied by lack of homogeneity in the concentration of the surrounding solid solution. This fact explains the increase in mechanical resistance and the occurrence of intergranular corrosion or cracking corrosion in some reagents occuring spontaneously or induced by the tempering of supersaturated solid solutions.

ALBERT PORTEVIN

Swedish Steel *made in* Electric Furnaces

STOCKHOLM, SWEDEN — The abundant supply of water power in Sweden and the almost complete lack of fossil fuel naturally caused an early interest in the possibility of employing electric energy for metallurgical purposes in this country. An interesting example is the invention of the first induction furnace by the Swedish engineer Kjellin, which was successfully worked at Gysinge as early as 1900. During the first 15 years of this century perhaps the main interest was devoted to the development of the electric blast furnace — also a Swedish invention; this work was greatly stimulated by an impending shortage in the supply of charcoal.

Production of Electric Steel

1915	2,000 tons
1920	12,000
1925	43,000
1930	116,000
1933	130,000
1934	164,000
1935	185,000

As seen from the table, the production of electric furnace steel did not rise to any considerable importance until after the War. At the present time about 20% of our steel is made in electric furnaces, the main part of the remainder being produced by the acid and basic openhearth processes (about 25 and 45% respectively). The rapid increase of electric steel incidentally coincides with the decline of acid bessemer steel, and also with the dwindling wrought iron production formerly so important.

Development of the arc furnace has followed the same general trend in Sweden as on the European continent and in America. The larger furnaces (15 to 25 tons) employ continuous Soderberg electrodes; at two works the Demag furnace has now been installed with removable cover and basket charging. Big tonnage production in 25-ton arc furnaces is to be seen at Domnarfvet, the largest of our steel works.

The introduction of high frequency induction furnaces has been just as rapid in Sweden as in any other country. They are used on the one hand for the production of those qualities formerly made in crucibles, on the other hand for the melting of 18-8 and similar high alloy stainless steels.

Experiments are now carried out with a new type of induction furnace introduced by the A.S.E.A. (Swedish General Electric Co.) and called the two-frequency furnace. In it the crucible is surrounded by two sets of coils; it is thus possible to employ simultaneously a high frequency current for heating the charge and a low frequency current (of say 50 cycles) for producing a vigorous stirring. Both currents may be regulated at will. The stirring causes the slag to become emulsified in the steel, and refining is very rapid.

Discovery of a sufficiently resistant refractory for the furnace lining seems to constitute the main difficulty, but experiments are being continued with great energy and it is hoped that these lining difficulties will be overcome. When working satisfactorily this furnace should be very useful and especially well adapted for Swedish conditions. At present the induction furnaces are charged with selected scrap, but because of the rapid refining action the two-frequency furnaces could preferably be charged with material with a high carbon content, consisting mainly of liquid pig iron directly from the blast furnace.

EINAR ÖHMAN

An Energy Method *for Determining* Relative Sliding Wear Resistance

PASADENA, CALIF. — The problem of determining the relative wear resistance of metals is probably one of the most difficult tasks confronting the engineer today, and many attempts have been made to devise a test for such properties. The principal difficulty has been in knowing what variables are of importance. Hence great care must be exercised when designing or selecting a machine for wear testing to simulate the conditions of service.

The present authors designed and built a machine at the California Institute of Technology in which the conditions of sliding wear were reproduced and which gave results commensurate with actual field tests, but tests made on this machine require considerable time and special specimens. Since one object of a laboratory test is to obtain comparative results in as short a time as possible under controlled conditions, we have endeavored to find an *accelerated* test by which the resistance of materials to sliding wear could be determined and correlated with service conditions. It is the intent of this paper to indicate a method whereby this objective might be reached. Preliminary tests have indicated that this method may give results which are correlative with the wear resistance, and it is the authors' hope that this note may bring about some discussion and further investigation.

Tests made by us on our special machine first mentioned, indicated that in most cases wear takes place by the scratching of one material on another, which in some cases (depending upon the material) formed a series of grooves in the direction of motion. We therefore concluded that valuable results might be obtained by observing the action of a hard point in scratching the surface of the materials under study. This at once brings to mind those methods for determining scratch hardness which have been devised by many investigators, notably Bierbaum. But the application of scratch hardness has not lead to any correlation with wear — as evidenced by work of other investigators as well as of the present authors.

In considering the mechanism of wear, it is apparent that energy is absorbed in friction, in the deformation and finally the removal of material from the specimen. It therefore seems reasonable that any test which may be devised to determine the energy absorbed in the process of wear will give correlative data. If a diamond point ground to the proper dimensions and loaded with the proper weight, be drawn over a polished specimen at a very low velocity (thereby cutting and removing material from the surface) a force will be necessary to move the diamond and can be measured with the proper instruments. Knowing the shape of the point, the width of scratch, and the force exerted, the energy necessary to remove a unit volume can be computed.

Investigations on scratch hardness have shown that the corner of a cube is the most satisfactory cutting point, wherein the diagonal is maintained perpendicular to the surface being cut, and the intersection of two of the cubic faces forms the leading edge of the cutting point. If the point is maintained in this manner, the depth of cut is proportional to the square of the width, and the volume of material removed is the product of the cross-sectional area and the length of travel. The work required to scratch is the product of the force and the distance moved. The work per unit volume

is then proportional to the force divided by the square of the scratch width, that is to say

$$E = k\frac{f}{w^2}$$

where E is the energy required to scratch per unit volume of material; f is the force required to produce the scratch; w is the width of scratch produced by the diamond point and k is a numerical constant.

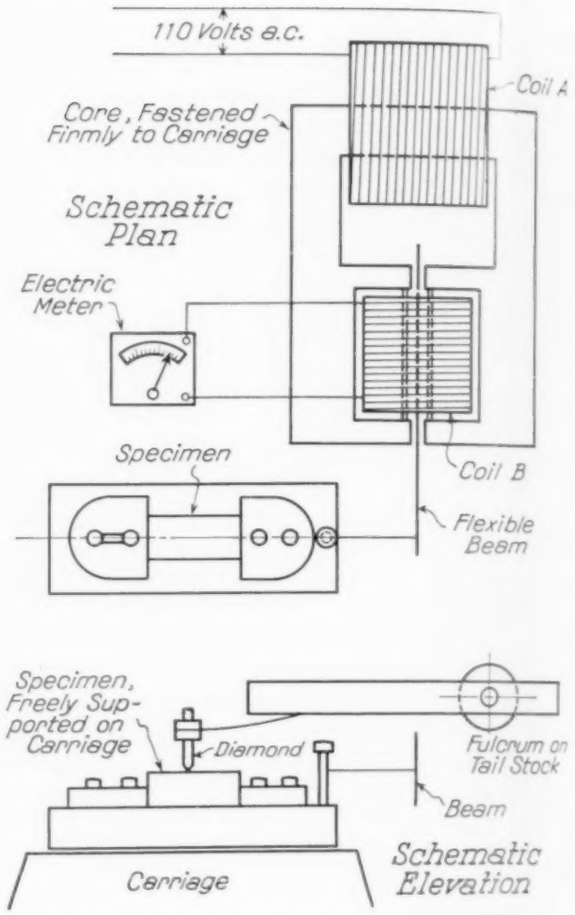
In our investigations the specimens were prepared as for metallographic examination and mounted on a holder which is freely supported on the carriage of a small lathe. The diamond is elastically mounted on the tail stock of the same machine. The specimen can then be moved under the diamond at a constant rate. The scratching force exerted by the diamond tends to move the specimen with respect to the carriage, but this movement is prevented by tying the carrier to a deflection beam fixed to the carriage. This beam is elastically held so that the deflection is proportional to the force required to move it, and is so mounted that it acts as an armature in a magnetic circuit. Its position may therefore be determined by the current induced in a coil surrounding the beam.

The magnetic circuit is calibrated with known forces on the beam so that the force required to scratch can be determined. The width of scratch is measured at high magnification with a filar micrometer. The energy is then calculated as indicated above.

Other work has shown that the relative hardness as determined by the scratch method may vary for different loads on the diamond point. For this reason various loads are used in determining the energy required to scratch. The energy can then be plotted as a function of the load and the results for various metals can be compared. Those requiring the greatest energy for removal of a unit volume of material should show the best resistance to sliding wear.

The method described in this paper differs from the work of previous investigators in that the force required to produce a scratch is employed in conjunction with the width of scratch made by the diamond of known dimensions. Heretofore investigators have attempted to make some correlation between the width of scratch and wear tests without success.

DONALD S. CLARK
Instructor in Mechanical Engineering
R. B. FREEMAN
Teaching Fellow



Amount of Force Required to Remove Measured Amount of Metal in Scratch Is Measured by Current Induced in Coil A by Deflection of Flexible Hold-Back

Some New Wear Tests

SCHWEINFURT, GERMANY — In metallurgical practice the question of the relationship of wear and hardness of steel frequently comes up. It may be stated thus: "Under what conditions does the indentation hardness correspond to wear resistance?" Karl Sporkert has answered this question very clearly in a recent issue of the German publication *Werkstattstechnik und Werksleiter* (May 15, 1936).

Dr. Sporkert studied, in the first place, eight hardened steels, all with high carbon and some alloyed with chromium or tungsten, heat treated to great hardness. Samples with about the area of a Johansson gage block were loaded with a given unit load and run for 15 min. against each of the iron and steel faceplates of a grinding mill. A summary of the results is given in the table, page 76.

The microstructures of these steels all

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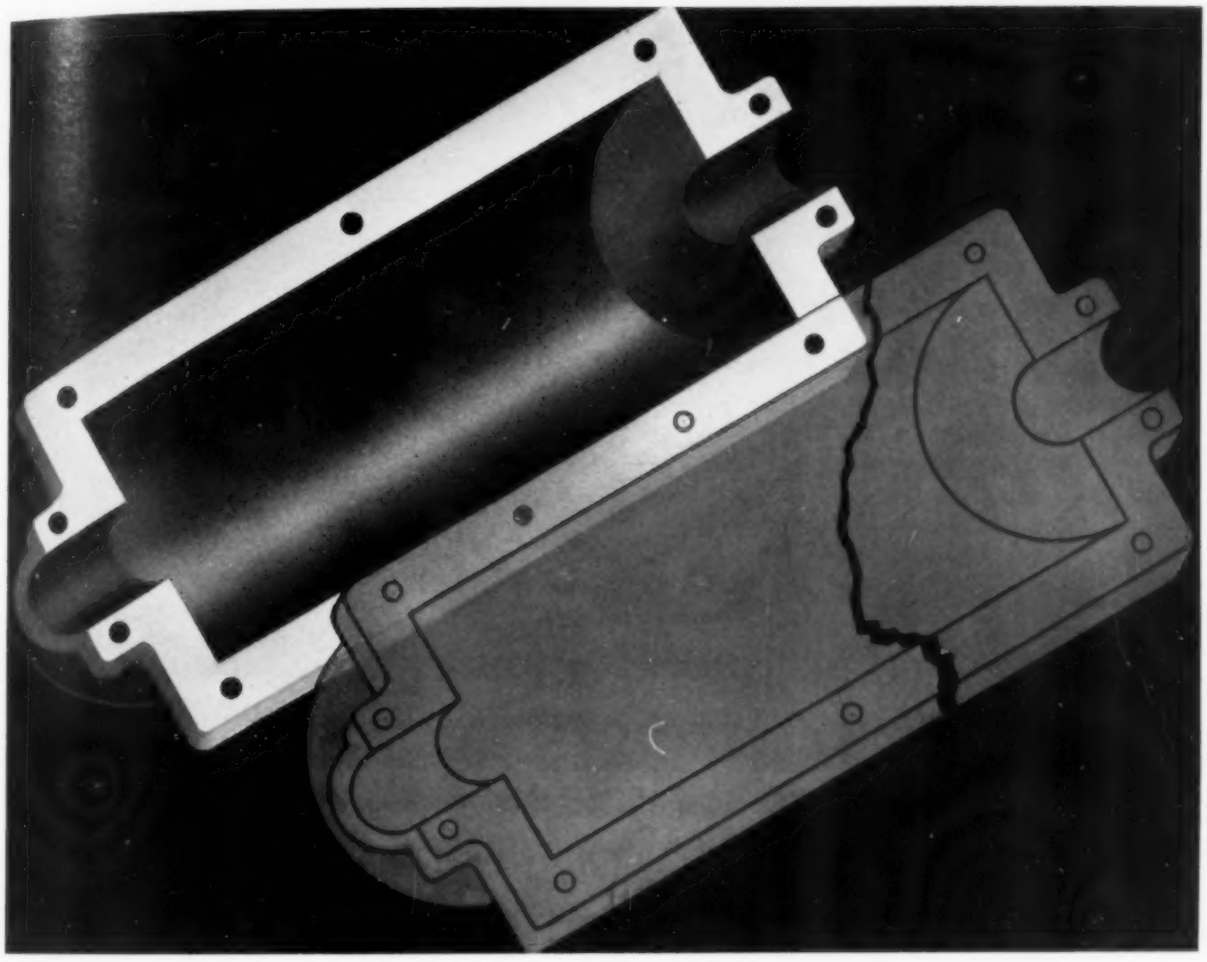

WHERE is the foundryman who has not encountered difficulties with malleable-iron castings due to primary graphite — especially in parts where coring prevents rapid cooling of heavy sections?

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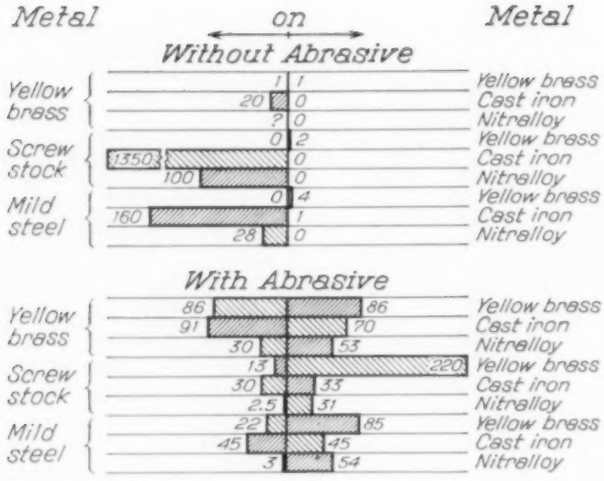


Results of Wear Tests of Common Alloys When Run Against Each Other. Crosshatched area and numbers represent amount of metal ground off in 0.01 mm.³ when running under controlled and equivalent conditions

showed excess carbide in rounded particles; in some steels the particles were larger than in others. The martensitic background in all but No. 1 and No. 7 etched very slowly; in these two the martensite had been tempered high enough so that the matrix etched darkly.

A study of the figures for relative wear, hardness and microstructure showed that the criterion of wear resistance of various hardened high carbon steels is the reciprocal effect between the grinding particles and the carbides in the steel. The more segregated or spheroidized carbide contained in the hardened structure and the harder these carbides are, the greater will be the wear resistance of the steel.

The Steel No. 4, as an instance, has four times the wear resistance of No. 1, even though the hardness is only one unit higher. However, the Rockwell hardness is a measure of the hardness of the *aggregate* — principally martensite — whereas the microstructure of steel No. 4 contains quite large particles of tungsten carbide (which is excessively hard). Again, steel No. 6 with hardness C-59.5 is softer than steel No. 2, yet it has a considerably better wear resistance, again due to larger and more numerous particles of chromium carbide in the microstructure.

A second series of experiments was made on sets of hardened and annealed steels of like analysis. In these experiments it was shown that the hardness of two materials sliding over each other is not the only criterion of wear, but the toughness and the tendency of the steel to pick up the abrasive are also factors. If the toughness of the test piece is greater than that of the roll or faceplate against which it rubs, the wear resistance of the test piece will be increased to such an extent that particles of the abrasive will occasionally adhere to its surface and act as a protection. If, however, the grinding material is embedded in the roll (as, for instance, in cast iron with its tough pearlitic groundmass and its securely anchored phosphide islands), the toughness of the annealed test piece is not as important as its hardness when looking for the criterion of wear.

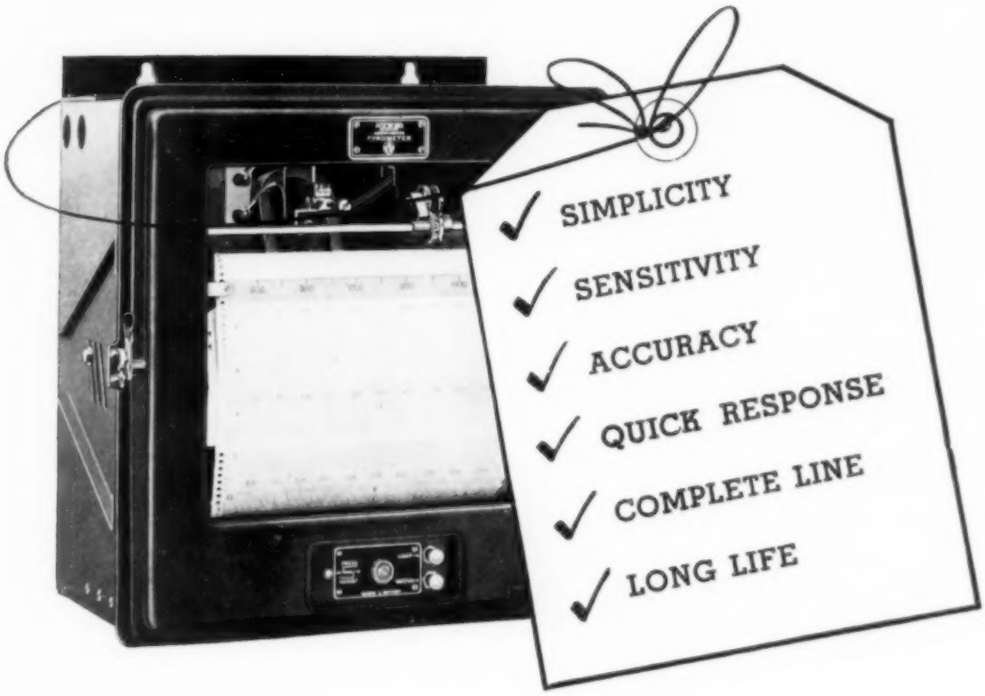
A third set of experiments to determine the wear of various materials used in machine construction was made on samples of yellow brass, cast iron, nitriding steel, red brass, free-cutting steel, and structural steel. Tests on various pairs of these metals showed that in the presence of loose abrasive particles between the surfaces, the tendency for them to adhere to the surface rather than the hardness of the material being tested is the criterion of wear resistance. (Diagram at the top of this page).

Steel	Analysis	Nature	Rockwell	Relative Wear
1	1.1%C	Water hardening toolsteel	C-65	102.7
2	1.1%C, 1.4%Cr	Ball bearing steel	C-64.7	100 (datum)
3	1.0%C, 1.5%Cr, 1.0%W	Oil hardening toolsteel	C-65	88.5
4	1.4%C, 3.5%W	Fast finishing toolsteel	C-66.1	23.6
5	2.0%C, 12%Cr	Die steel	C-64.5	36.5
6	0.6%C, 13%Cr	Stainless cutlery	C-59.5	73.7
7		Johansson gage	C-65	108.5
8		Zeiss gage	C-64.2	107.5

It should be noted that even if no abrasive medium is used, one is produced automatically in the form of a metallic powder, either because the lubricant occasionally does not cover the entire metal surface, or because solid grains are carried with the lubricant between the sliding surfaces. It should also be noted that friction oxidizes the metal parts, and iron oxide acts as a good abrasive (for instance, rouge).

HANS DIERGARTEN

Let's check what you need in a PYROMETER!



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ACCURACY FOXBORO RESPONSE

Personals

Harold Stein has been appointed research engineer of the manufacturing department of Allis-Chalmers Mfg. Co., Milwaukee.

T. Heske has been made production manager of Summerill Tubing Co., Bridgeport, Pa.

E. J. Edwards has been promoted from engineer of tests to chief metallurgical engineer of American Locomotive Co., Schenectady. **L. F. Mulholland** is now engineer of tests.

Samuel Epstein, until recently research metallurgist at Battelle Memorial Institute, has joined the research and development department of Bethlehem Steel Corp., Bethlehem, Pa.

Chester L. Wells has been appointed advertising representative of **Metal Progress** in the eastern states.

H. P. Munger, formerly with the American Rolling Mill Co., is now metallurgist in the research department of Republic Steel Corp., Warren Works.

George B. Waterhouse, professor of metallurgy at Massachusetts Institute of Technology and vice-president-elect of American Society for Metals, is abroad, and will attend the meeting of the Institute of Metals in Paris and the meeting of the Iron and Steel Institute in Duesseldorf.

Robert S. Rose has been transferred to Boston as sales representative for Vanadium-Alloys Steel Co. and Colonial Steel Co.

Charles Hardy of Charles Hardy, Inc., has returned to New York after a two months' stay in Europe.

Harry L. Campbell, who has been at the University of Michigan for the past 15 years, is now employed as metallurgical engineer at the American Hoist and Derrick Co., St. Paul.

M. H. Mawhinney has terminated his association as consultant with the Salem Engineering Co., Salem, Ohio.

J. E. Wilson has resigned from the Kelvinator Corp. to become metallurgist with Bausch & Lomb Optical Co., Rochester, New York.

George C. Congdon has been appointed manager of advertising and sales promotion, and **R. M. Gibbs** assistant manager of advertising of Jones & Laughlin Steel Corp.

Karl L. Fetters is now with the metallurgical department of the Youngstown Sheet and Tube Co., Youngstown, Ohio.

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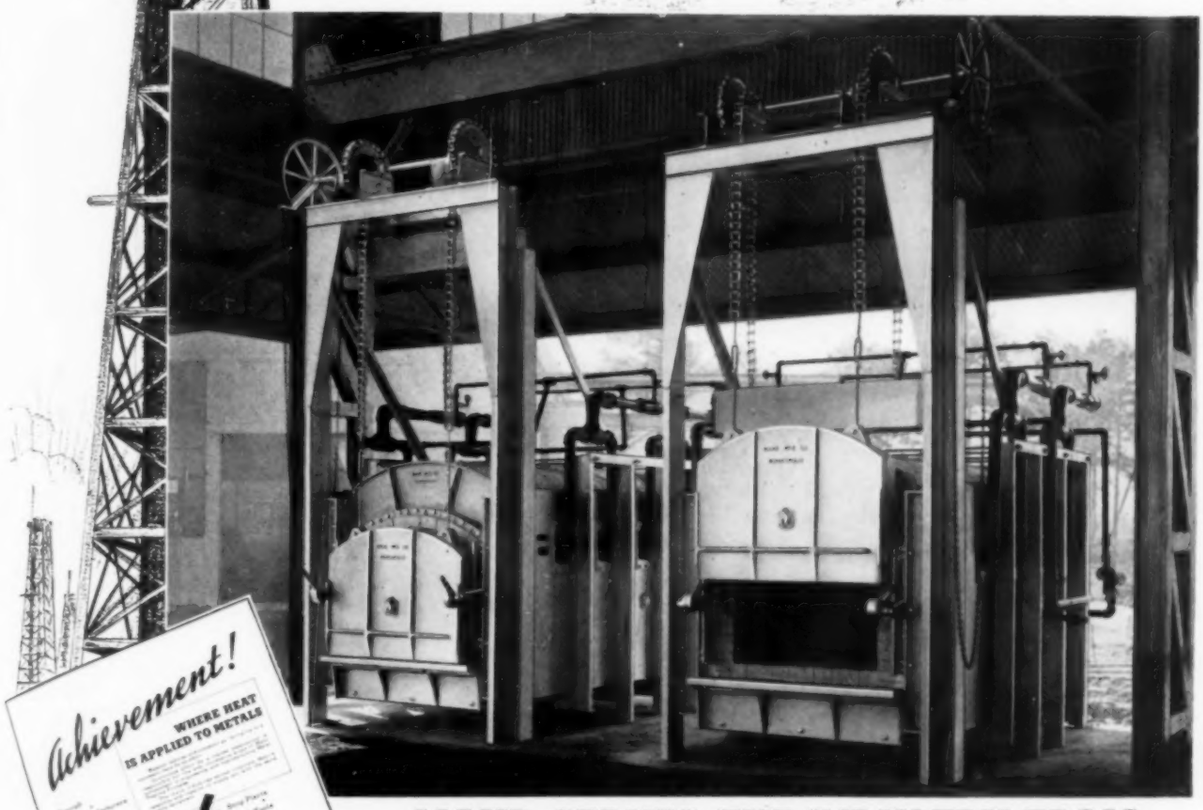

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Personals

Ira S. Latimer, formerly metallurgical engineer, Follansbee Bros. Co., is now chief metallurgist, Rotary Electric Steel Co.

George H. Fisher is now in the metallurgical department of the Great Lakes Steel Corp., Ecorse, Mich.

Norman L. Mochel, metallurgical engineer, Westinghouse Electric and Mfg. Co., has been given the Westinghouse Award, Order of Merit, "for distinguished service to the industry in the field of metallurgy."

J. M. McKibbin has been appointed manager of a newly created sales promotion department of the Westinghouse Electric and Mfg. Co.

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Myron H. Clark has been made chairman of the Associated Management Counsel, an organization of business consultants and managers.

James H. Herron, president, James H. Herron Co., Cleveland, has been nominated for president of the American Society of Mechanical Engineers.

Wm. G. Van Note is returning to North Carolina State College as assistant professor of chemical engineering, after a year's leave.

Frances Hurd Clark, metallurgist for the Western Union Telegraph Co. in New York City, was married on June 27 to **Robert L. Dietzold**, a member of the technical staff of the Bell Telephone Laboratories.

H. Foster Bain has become associated with **Samuel H. Dolbear** and **Lawrence B. Wright**, mining engineers in New York City.

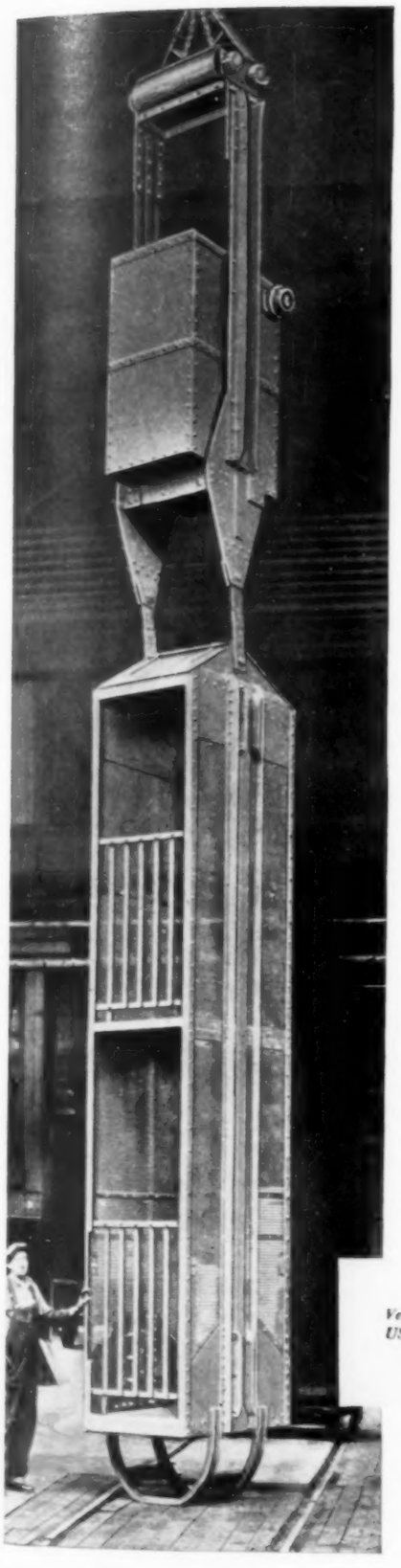
William Mogg is sales engineer in the transportation department of the Ohio Brass Co., Mansfield, Ohio.

George W. Keller, formerly vice-president of Brown Instrument Co., is now in charge of the eastern sales division of the Wheelco Instruments Co., Chicago. **Elmer A. Schneider**, formerly owner of the Mishawaka Pyrometer Instrument Co., is now production manager for Wheelco in Chicago.

Bernard R. Queneau is associated with the Research Laboratory of United States Steel Corp. at Kearny, N. J.

Elmer B. Hauser has been made research metallurgist for the Weldon Tool Co., Cleveland.

K. A. Newman has left E. F. Houghton & Co. to become manager of the lubrication division of Specialty Products Co., Jersey City, N. J.



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UNITED STATES STEEL

Heat Treatment

in a

Magnetic Field

by R. M. Bozorth and J. F. Dillinger

Condensed from Physics and Electrical Engineering

IT HAS BEEN KNOWN for many years that the magnetic properties of iron and silicon steel are somewhat changed by heat treating in a magnetic field. During the early experiments with perminvar it was found that the constant permeability for which this material is best known could be obtained only when there was no field present during the heat treatment, and that when a field of one oersted was maintained during annealing the maximum permeability at room temperature was 136,000 instead of the usual value of 1500. More recently it was found that the hysteresis loops for these specimens had square corners and vertical sides.

In recent work, a series of iron-nickel alloys was tested in the form of small rings, annealed in hydrogen at 1835° F. and furnace cooled. Next the ring was annealed 100° F. above the Curie point for 1 hr., and during furnace cooling a magnetizing field of 16 oersteds was applied. Tests then showed that the maximum permeability (275,000) was found in a 68% nickel alloy, and this is the alloy with the highest Curie point (1050° F.). Compare this with the maximum permeability of this series of alloys, rapidly cooled without an applied field, of 90,000 for the 78 permalloy (78% nickel-iron).

By applying the magnetic field at various stages during cooling it was found to be effective from just above the Curie point, where the alloy becomes magnetic, down to about 750° F., the lowest temperature at which internal rearrangement (recrystallization or diffusion or plastic flow) takes place rapidly enough to be noticeable, but most effective in the range 950° to 750° F., provided the Curie point of the alloy is above the first mentioned temperature.

Calculations from experiments with relaxation time and plastic flow indicate that the lowest temperature at which the heat treatment is effective can be identified with that at which plastic flow begins to occur as the result of the forces brought into play by magnetostriction. (When a rod of iron is magnetized its length increases by a small amount and its diameter correspondingly contracts. This is but one example of a large class of effects exhibited by all ferromagnetic bodies where the metal deforms without change in volume, effects known collectively as "magnetostriction." There is also a close converse relation between external stress, internal strain and magnetization.)

Our data all support the plastic flow hypothesis mentioned at the outset of the paragraph just above, provided we can show how plastic flow in the presence of a field increases the permeability in the direction of that field. In order to understand this, a more detailed consideration must be given to the changes that occur in the local strains, and their relation to the changes in magnetization.

We start with the idea, proposed by Weiss many years ago, that a magnetic material is composed of small domains, whose volume is on the order of a 0.001-in. cube, in each of which the material is magnetized to saturation in some direction. In iron and 65 permalloy this direction is one of the cubic axes of the crystals. In an unmagnetized polycrystalline specimen, in which the crystals are oriented at random, some domains are magnetized in every possible direction. As the field is applied in a certain direction, the magnetization of these cubic crystals in most of the various domains changes by 90° or 180° to another crystallographic axis more closely aligned with the field.

Now consider what will happen to these regions as the material is heated above the magnetic transformation point. More specifically let us take a region assumed spherical, for convenience, which is above the magnetic transformation point, but which will form a magnetized domain when cooled below this temperature; it will then became magnetized along one of the cubic axes, but as it does so it will tend to change its shape. If time is allowed, it may actually assume, by plastic flow of its neighbors, the ellipsoidal shape appropriate to magnetostriction; or, it may do the equivalent thing and flow plastically within its own boundaries relieving the magnetostrictive stresses in this way.

Suppose when the material is cooled to room temperature it is magnetized in a direction almost opposite to the one this specific domain naturally assumed during slow cooling. The magnetization in this domain will then reverse by 180° to one of its other stable positions more closely aligned with the field. No change in shape will occur during this change in magnetization. If, however, still at room temperature, we apply the field in the direction normal to the last mentioned, the domain will change its magnetization 90° along another axis of the cubic crystal and tend to change its shape. But

(Continued on page 86)

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OPTICAL INSTRUMENTS • METALLURGICAL APPARATUS

Heat Treating Magnets

(Starts on page 82)

this change will be opposed by the mechanical constraints due to the surrounding material.

If in another experiment the material is cooled rapidly enough through the magnetic transformation point down to a low temperature, there will be insufficient time for any change in shape to occur by plastic deformation and the domain will maintain more or less its original spherical form. In such a condition the magnetization of the domains may change by 90° or 180° with equal facility, whereas in slowly cooled material the domains can change by 180° easily but by 90° only with great difficulty. This case can occur, for example, in 78 permalloy, the permeability of which is higher after rapid cooling than after slow cooling; the additional probability of 90° rotations increases the number of domains which can easily be aligned with the applied field.

The effects of slow cooling **within a magnetic field** are now predictable. When the polycrystalline material passes the Curie point, the domains will align themselves as nearly as possible with the field, consistent with the restriction that they must be magnetized in one of the easy directions — that is, along a cubic axis of the crystal. The strains produced by magnetostriction will be relieved if temperature and time allow, allowing the domains to assume shapes that permit very easy magnetization in the same direction (or reverse direction to that imposed during heat treatment) but offering large mechanical resistance to magnetization at 90° to this direction.

For expository purposes the spherical domains were assumed above to become spheroidal by magnetostriction. The theory also holds for the alternative assumption that either the boundaries of a domain are changed by plastic flow or the material inside adjusts itself to the unchanged boundaries. Considerations as to relaxation time indicate that it is only necessary for readjustment of atom positions to occur within regions containing a few atoms for the whole domain to become stress-free.

[Some confirmatory evidence for this theory is from an X-ray investigation of lattice distortion at the National Physical Laboratory, England, and reported in its 1935 year book. In permanent magnet steels one condition which tends toward a high coercive force is the presence in the crystallites of a high degree of lattice distortion, while in transformer steels such distortion should be absent if a low hysteresis loss is to be obtained. In addition, in transformer steels the X-ray analysis suggests that it is advisable to prevent as far as possible the breaking up of the individual crystallites into mosaics whose components differ slightly in orientation.]

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Permanent Magnets

(Continued from page 68) tion of the first mentioned, the data so far reported on these materials vary rather widely both as to composition and properties. Standardization into a few recognized and useful types for commercial applications has not yet been accomplished and probably will not be until considerably more exploratory work has been done.

Of the above alloys, *(a)* has the advantage of slightly higher coercive force and residual induction than 36% cobalt steel, greater machinability, slightly lower density and lower cost. It has the disadvantage of greater brittleness. Alloys *(b)* and *(c)* have coercive forces much larger than those of 36% cobalt steel and residual inductions hardly as high, with still lower density and cost, but they have the disadvantage of being neither forgeable nor machinable. Their use is therefore confined to magnet designs which can advantageously be cast.

The above alloys may, under proper conditions, be made to produce good magnets in the cast condition without further heat treatment, but in general, a high temperature solution heat treatment terminated by an oil quench and followed by a precipitation heat treatment is required for best and most uniform magnetic quality. The iron-cobalt-molybdenum alloy is machinable before and after the solution heat treatment, but not after the precipitation heat treatment.

It is possible to make magnets by the process of compressing and sintering the powders of the constituent metals. This process may also be applied to the production of magnets from the oxides of the constituent metals. The metallic oxide magnets have the peculiar property of being greatly improved by being magnetized at an elevated temperature, and the improvement persists for subsequent remagnetizations at room temperature. Nominal magnetic properties of magnets made of iron and cobalt oxides are B_r=4000; H_c=300 to 1000.

Other alloys which have been reported include an iron-platinum alloy with coercive force H_c of 1800 oersteds and a residual induction B_r of 4000 gauss, an alloy of neodymium with iron having H_c=4300 oersteds and a silver-iron alloy with H_c= 5000 oersteds. In these cases the residual induction is so low as to preclude the possibility of commercial usefulness.

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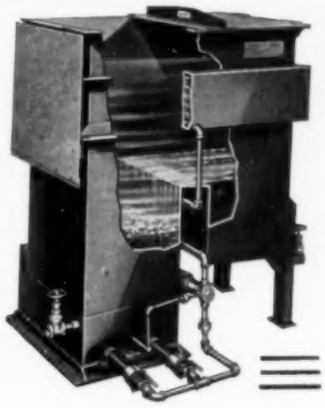

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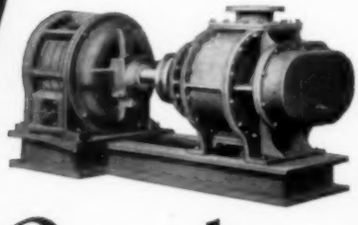

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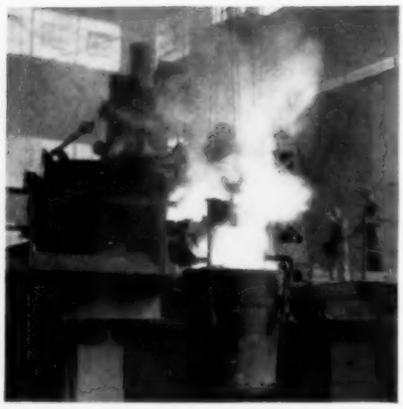

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Grating Spectrograph

(Continued from p. 63) film exposure is obtained by stopping down the grating. Provision was made to handle a continuous strip of film containing, say, 10 or 20 determinations, to facilitate development. The quantitative system employed was particularly suited to mass production, as it did not necessitate any controlled development or calibration of film, as is the case in those employing photometers. In analyzing the films, four aluminum lines and four attendant iron lines were measured, ratios calculated and the alumina contents obtained from a graph prepared once and for all with standards. The averaging of four independent readings on aluminum and iron made for an accuracy much better than 90% of the alumina content.

Extensions of this technique should eventually include the determinations of silicon, calcium, magnesium, and manganese — all from a single film. This is possible, since all of these elements occur in this ore in the order of 1.0%. Minor constituents such as titanium, chromium, and zinc would require a separate arcing operation and spectrogram, since the sample in this case could not be diluted. For these elements, occurring in the order of 0.01%, the accuracy would probably be greater than that attained by chemical methods.

One other application is worthy of comment, namely the use of the spectrograph in mineral survey work or prospecting. Its high general sensitivity and the wide range of elements detectable provide approximate analyses of much value. In fact, this method is accepted in Southern California by engineers and assayers alike as an economical and thorough method of investigation, and service is maintained by several laboratories utilizing the equipment described above. Routine procedures are employed which assure accuracy and allow analyses to be made at a price comparable to other methods offering much less adequate results.

In metallurgy and its sister industry, mining, the spectrograph is assuming a role of greater and greater importance. The ultimate goal, of course, is to establish a simplified general spectrographic method which will transcend many of our present chemical methods and bring analytical spectrography to the high position it so rightly deserves.

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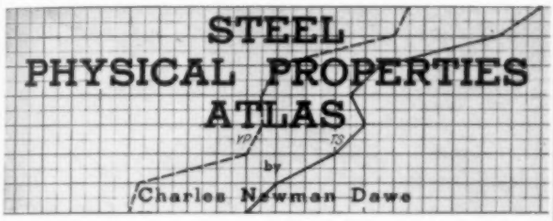

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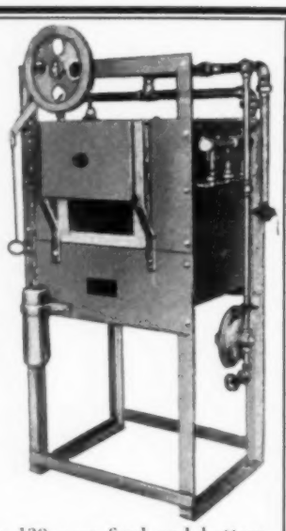

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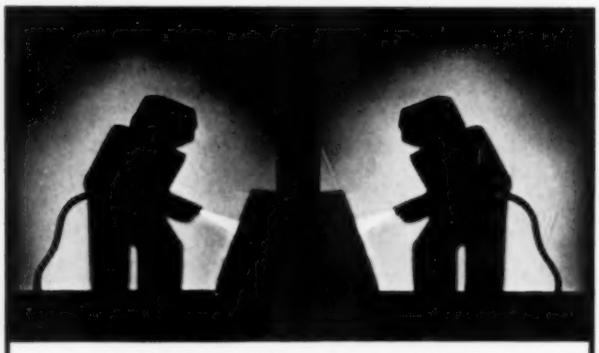

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Appraising Sheet Metal

(Continued from page 48)

rolled according to a definite type of rolling treatment can be held to a satisfactory uniformity of drawing quality by holding to set limits of other physical properties, particularly hardness and dynamic ductility. To compare different types of zinc, it has been found absolutely necessary to make either a true drawing test or to conduct a commercial trial.

Several of those present at the above discussion mentioned the matter of grain size. The conclusions of a topical discussion held by an A.S.T.M. subcommittee on Sheet Steel (A. L. Davis, chairman) are of interest in this connection.

1. Production and use of cold-rolled sheet and strip made of "inherently fine-grained" steel is in an early stage, and verified data are meager.

2. In some instances superior properties have been obtained from "pre-aged" or "fine-grained" steel, which justify its use for special purposes. There seems to be no advantage in its general use.

3. Today several producers are in a position to furnish "fully killed," "pre-aged" or "stabilized" steel in sheet or strip, but such material is somewhat more costly and hence is not used where ordinary rimming steel gives satisfaction. The freedom from strain aging is advantageous, but roller leveling of rimmed steel sheet before fabrication accomplishes the same end.

4. Other things being equal, the finer the grains of ferrite the smoother the surface of the formed part made therefrom. Also, the finer the grain the higher the yield pressure and the greater the forces required for stamping and drawing. In spite of this greater hardness, instances have been recorded of deep draws made with fine grain.

5. When talking about grain size, it is necessary to distinguish between the **actual** grain size and the **inherent** grain size. Thus, with ordinary rimmed steel we may have cold-rolled steel of remarkably fine grain, due to its history of processing. Actually, cold-rolled strip steel generally is of quite fine grain, as supplied by the producer. Thus a fully killed steel of inherently fine grain may not be notably finer in actual grain size than the corresponding sheet made of rimmed steel, though it always is somewhat finer.

6. "Inherent grain size" refers to the austenitic grain size resulting from a specified heat treatment. It will be modified by subsequent hot work and by cold work, and also by annealing. Thus, the actual grain size in commercial cold-rolled sheets and strip steel does not necessarily indicate the "inherent grain size." It is not yet known to what extent the superimposed effects of hot and cold work and annealing overshadow the "inherent" properties of the steel.

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The cost of an INSULCRETE lining is moderate, in terms of cost of material per **cubic foot.** And it is very economical to install—no cutting, no ramming—**just pour into place.** INSULCRETE can be poured or cast in a fraction of the time necessary to lay brick or ram in plastics. Service cost is low because of long life (excellent refractory properties). Saves time and labor in faster heating-up—reduced lag between operating cycles—faster rate of output.

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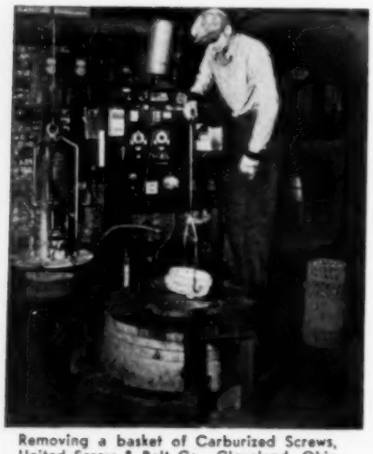

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HEAT TREATING FURNACES

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Porosity in Tinplate

(Continued from p. 55) by an optical method, is sufficient to penetrate to the compound layer intermediate between pure tin and steel base, and crystals of $FeSn_2$ were seen in some of the depressions.

Scruff bands are defined as narrow bands in which the tin coating is contaminated by the inclusion of minute particles of scruff or $FeSn_2$, which are visible as microscopic excrescences in the coating. The bands run across the sheet at right angles to the direction of tinning.

Scruff bands have been seen on all samples of tinplate so far examined carrying less than about 2 lb. of tin per base box; they have not been detected on tinplate carrying more than 3.5 lb. of tin. They are usually discernible on finished plates, but can be seen more readily on sheets withdrawn from the top of the grease-pot prior to cleaning. Scruff bands appear on both sides of the tinplate, although not coincident in position. The average distance apart is related to the roll diameter and number of teeth in the driving pinion, suggesting that irregular impulses, produced by chatter of the grease-pot rolls, or by slight periodic slip between the rolls and the tinplate surfaces, are responsible. By continued contact with molten tin, these rolls acquire a loosely adherent coating of iron-tin alloy crystals, some of which would tend to be transferred to the tinned sheet by variations in pressure or uneven movement of the rolls, thus forming scruff bands.

Transverse ripples are defined as narrow channels (about 0.020 in. wide) in the tin coating, running in a direction approximately at right angles to the direction of tinning; they are fairly sharply delineated and easily visible. They are usually wavy or curved and may occur singly or in groups of two or more close together.

The maps suggest clearly an association of pores (actual and potential) with scruff bands. This may be due to one or more of the following causes: (1) Periodic thinning of the molten tin coating by irregular movement of the sheet with respect to the rolls, which may rupture the film of tin bridging crevices that are not filled with tin or covering areas that are not wetted with tin. This suggestion would imply the presence of such areas over the whole surface of the sheet. (2) Local exposure of the intermediate alloy layer, due to deficiency of tin (as, for example, in grease marks). This alloy layer has been shown to be highly porous. (3) The presence of crystals of hard iron-tin alloy (scruff) in the soft tin coating may be a potential source of porosity. Many examples of iron-tin alloy crystals of a width greater than ten times the thickness of the tin coating have been seen. Handling or cleaning of the sheet would be likely to dislodge such crystals, leaving gaps in the coating.